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FOREWORD

The State of Punjab is known for its canal irrigation system. The rudiments of this system existed even before the extensive modern canal system was established at the fag end of the 19th century by the British Government. In the wake of partition of the country a major part of the canal system went to the share of Pakistan and only three canal systems i.e. the Upper-Bari Doab, the Sirhind Canal and the Western Jamuna Canal fell to the share of Punjab (India). In order to meet the great demand for irrigation, steps were taken to improve the old canal system and to construct new canals. The construction of the Bhakhra canal system is the biggest landmark in canal-irrigation development in Punjab after independence.

The Punjab State has done excellent work in the canal irrigation system. But the information about it is available only in a scattered manner and is not available in the form of a concise booklet which could be of interest not only to the students of Engineering and Agriculture, but also to the persons interested in the general information on this important aspect of our development.

Dr. G.S. Dhillon who has served as Professor of Civil Engineering in this University after his retirement as Chief Engineer Research-cum-Director, Irrigation and Power Research Institute, Punjab, Amritsar, has a rich experience of this subject and is eminently suitable person for writing this bulletin. He has very speedily completed the writing of this book. I am confident that this will fulfill a long felt need of the engineering students in particular and the public in general. I commend this publication as a text for all agriculture and engineering colleges, particularly in the northern states of the country.

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PREFACE

Information pamphlets are usually issued by the Punjab Irrigation Department when any official function is arranged for the laying of the foundation stone or commissioning of a project but these publications give only limited information. There is no agency which a person can approach to know about the Punjab canal system or to get these information brouchers.

The need for such a publication which could provide complete information on Punjab canal system was keenly felt while teaching canal engineering course to the agricultural engineering graduates in the College of Agricultural Engineering of Punjab Agricultural University, Ludhiana. I discussed this matter with the Vice-Chancellor who encouraged me to write this book.

Dr. S.D. Khepar, Dean, College of Agricultural Engineering has rendered a great help in finalising this bulletin.

I hope this bulletin will prove very useful to both the engineering students and the general readers. There is always a scope for further improvement. The suggestions of readers will help a lot in improving its revised edition.

G.S. Dhillon

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1.0 INTRODUCTION

The Punjab State, the land of five rivers, got partitioned on August 15, 1947 into the East Punjab (India) and the West Punjab (Pakistan). Once again on Nov. 1966, the State got re-organised on linguistic basis and the State of Haryana came into being. Certain hilly areas went over to Himachal Pradesh which enabled it to gain full statehood. The reorganised Punjab has an area of 50,362 sq. km. and as per 1981 census it has population of 167 lakhs, 72.4 per cent of which lives in its 12,342 villages. The State lies between longitudes of 73.9° and 76.7° and latitudes of 29.5° and 32.5° north. (See Figure 1).

The climate of the State ranges between arid and semi-arid, with an average annual rainfall of about 75 cm, most of which occurs during the monsoon season.

As regards the land use, 83 per cent of the land is under cultivation, 4 percent under towns, road, rail, etc. and hardly 1 percent is lying fallow. About nature of the soil, it can be broadly stated that the plains have been built during successive geological eras, by the rivers which flowed through the area. Between the foot hills and alluvium plains lies a distinctive belt, called *babar* which is a predominant plain in which coarse pebbles are intermixed with fines making extremely pervious detritus. The deposits along the banks of the rivers in flood plains, known as *bet* areas are generally sandy, light in colour and contain a small percentage of calcareous nodules (*kankars*). The deposits further away from the rivers are called *bangar* and form high ground. The nature of soil in these areas is clayey and dark in colour and full of *kankars*. In between the *bet* and *bangar*, the soil consistency ranges from fine silts to stiff clays. Occasional feature of the alluvium is the presence of 'hard pans' at certain depths in the soil profile and this is caused by infiltrations of silica or calcareous matter, resulting in formation of kankar beds. Occurrence of hard pans impedes the penetration of plant roots and also affects the percolation of water. The regional slope is mainly towards south-west. Geologically speaking, the alluvial soils of Punjab

are very suitable for irrigation as they give good response to the artificial watering of crops and inspite of the river vagaries and human misuse, the alluvial soils of Punjab form one of the most fertile soils supporting the most densely populated region, and sending food grains to the other areas.

1.1 River System

The pre-partition Punjab was covered by the river Indus and its tributaries; the river Jhelum, the river Chenab and the three eastern rivers of Ravi, Beas and Sutlej (See Fig. 1). All these rivers are briefly discussed next.

The mighty river Indus with average annual flow of one hundred million acre foot (MAF) rises north of the Mansrowar lake in Tibet and flows through north-western direction for a distance of about 650 kms. Thereafter, it takes a sharp turn towards south through Bunj gorge and then flows past Nanga Parbat. The tributaries which join during its flow course in mountains are Zaskar, Dras, Astor, Shyok and Shigar. The tributaries which join in the plains are Jhelum, Chenab, Ravi, Beas and Sutlej. The river Jhelum flows through Kashmir from its source at Verinag and crosses the Pir-Panyal through a deep gorge. It receives waters of the tributaries of Liddar, Sind and Poonch, all of which rise in Kashmir beyond Wullar Lake. The river Jhelum thereafter passes down a deep gorge at Khadanyas and is joined by Kishan Ganga on the right. About 400 kms from its source, the river Jhelum flows past the Jhelum Town and finally joins the river Chenab at Trimnu about 320 kms lower down.

The River Chenab has as main tributaries the rivers Chandra and Bagga which rise in Lakaul and cross Himalayan range to join the main river in Kashmir. About 250 kms from its source, it emerges from the foot hills into plains at Akhnoor. Downstream of this point, it starts spreading into a greater width.

The river Ravi rising in Kulu flows west wards through a trough formed in the knot of mountains where Pir-Panjal and Dhaladhar mountain ranges meet. It enters plain near Madhopur. The river then flows along Indo-Pak border and enters Pakistan some distance above Lahore which lies on its left bank. The river outfalls into the river Chenab.

The River Beas rises from Himalayas and flows in the westerly direction and enters plains near Talwara. Near Mirthal river takes sharp bend and flows toward south-west and has its right bank high where left bank is low. It flows past Dhilwan, Goindwal Sahib and joins river Sutlej above Harike.

The river Sutlej rises near Dharma Pass on the Zaskar and flows through Tibet Plateau and then cut through the Himalayan range entering plains near Rupar. It receives water of the river Beas at Harike and then flows past the town of Ferozepur and joins the rizer Chenab.

2.0 IRRIGATION SYSTEM—ITS HISTORICAL DEVELOPMENT

The irrigation development in the region has a long history which dates back to Indus Civilization, when comparatively small group of men started settlings down, as village communities, whose main source of subsistenee was agriculture. The village communities, in the early phase, settled along the river banks where the annual inundation of land coupled with the timely rainfall provided enough moisture for raising crops. This type of irrigation came to be known as 'Sailaba' and was then the main form of irrigation. It covered a small width of land on either side of the river edge.

Later on the genius of some poineers hit upon a brilliant idea of carrying water to distant lands, by utilising some abandoned creeks of rivers.

As population grew and need was felt for bringing more land under cultivation, excavation of artificial channels, inundation canals, to carry water to land far from the river edge originated.

2.1 Well-built inundation canals existed in early seventeenth century. Buckley R. B. in his publication entitled "Irrigation works in India and Egypt" published in 1893 from London, describes the position as follows :

> "The district of Multan (now in Pakistan) lying between the Sutlej and Chenab, where rain hardly falls, is rendered beautifully fertile by a series of inundation canals taken from both rivers which are said to have been originally

constructed by Afgan ruler Aurangzeb who reigned from 1658 to 1707 A.D."

"The upper Sutlej inundation canals are in the central portion of the doab, lying between the Sutlej and the Ravi. Here face of country is covered with traces of former life and prosperity. The cause of decay was due to the loss of water supply, consequent upon the diversion or change of course of the river Beas, which formerly had an independent course to Chenab, to fertile land on either bank. But in 1790 A. D. it got diverted into the Sutlej near Harike because of natural irrigation. The old bed consequently became dry ravine with a complicated system of deserted water courses."

2.2 Of some of the ancient inundation canals which need to be listed here are, Hansli Canal of the river Ravi and Shah Nehar of the river Beas. The former was built by Emperor Jahangir to take water of the river Ravi to his fort and hunting ground near Sheikupura (now in Pakistan), by digging a 80 km. long canal, where he had built a garden and a reservoir at Hiran Minar. Later around 1633 A. D., Ali Mardan Khan, the celebrated engineer of Emperor Shah Jahan built another canal, known as 'Hansli' off taking from the left bank of the river Ravi and this canal carried water to Shalimar Garden at Lahore. This was 177 km long, 9 m wide and had a discharge of 14 cumecs. It irrigated a part of the Bari Doab in the process. During the Sikh Rule (1763-1849 A. D.) a branch of this canal was constructed to carry water to the Golden Temple at Amritsar. During that period, the area irrigated by Hansli was 12,500 hectares which brought an annual revenue of Rs 85,000 to the treasury of sikh rulers.

Shah Nehar, an inundation canal was built during Mughal period, around year 1744 A. D. by private enterprise, village money lenders to irrigate lands on the left bank of the river Beas around Mukerian. The canal had its off-take located near village Rey, about 24 km from Mukerian and comprised of a number of smaller canals, such as Sathwan, Ladhri, Ajmeri, Naushera and Shah Nehar itself. Grey canal system of inundation canals was remarkable as it constituted the first

inundation canal system built during the British Rule and which was designed on scientific lines. These canals off-took from the reach of the river Sutlej between Phillaur and Ferozepur and were constructed by the then Deputy Commissioner, Ferozepur Col. I. J. H. Grey, in 1875-76. In all there were eleven canals to start with and in 1883 two more were added to the list. The total discharge utilised by all these canals was about 6286 cusecs (178 cumecs) and their length amounted to 1655 kms. Col. Grey, in 1885, pulished a 'Manual for Construction and Management of Ferozepur District Canals' and this manual provided guidance to the officers concerned regarding excavation of inundation canals on scientific principles of planning, which were based on experience gained by the author on construction and operation of the Grey canal system. The design criterion was based on slope and hydraulic mean depth of the channel. The system benefited an area of 425,000 acres (position in 1947).

Ghaggar canal system of inundation canals, comprised of Northern Gaggar canal and southern Ghaggar canal which took off about 8 miles below the town of Sirsa, from the river Ghaggar. The flow in Ghaggar was mainly dependent on rainfall during summer months. A masonry weir had been built across the lower end of the Dhanura lake and two canals mentioned above took off from that location. Each canal had its distribution system and served a gross area of 102,785 acres, (position in 1947-48). The area covered lay in Hissar district mainly. As the supplies were not only very erratic but insufficient so the area was included in the Bhakra canal system, after suitable remodelling. The intensity of irrigation rose to 77063 acres in 1963-64 compared to 13,321 acres of irrigated area in 1947-48.

The Sarusti canal system, an inundation canal, was built as far back as the year 1895-96 by the District Board Karnal according to the design furnished by the Irrigation Department, on the Markanda rivulet. A bund was put across at the downstream end of the Bibipur Lake which was fed by both Sarusti and Markanda streams. The Sarusti Canal System with its para Minor and Bhona Jheel, served a gross area of 188761 acres of Kaithal Tehsil (now in Haryana). The culturable commanded area was 154,880 acres in the year 1947-48. The supply of

water was, however, very uncertain. This area was also switched over to the Bhakra System and came to be served through Narwana Branch. The ranking of the area changed over from Inundation canal area to restricted perennial area raising its annual intensity to 45 percent. The canal system was completely remodelled. The area began receiving Sutlej waters in 1954 and its annual irrigation increased to 83,452 acres in 1963-64 compared to irrigated area of 28,785 acres of uncertain irrigation in 1947-48, an increase nearly three fold. The Khands or inundation canals off-taking from the Bhupindra Regulator (also called Devigarh Regulator) built in the year 1932 by Maharaja Bhupindra Singh of Patiala State, were Hazipur Khand Adalliwala Khand, Dudhan Khand and Ghuram Khand. The regulator was located on the river Ghaggar at the crossing of Patiala—Pehowa Road. The regulator had been designed for a maximum flood of 10,000 cusecs and provided water way of 120 feet (six bays of 20 feet clear). For regulation wooden needles (vertical beams) were used. There was drop of 10 feet clear available in the bed of the Ghaggar. During construction of the Bhakra Canal System the area of the Khandas of Hazipur, Adalliwala, Dudhan and Ghuram was transferred to Ghuram Distributory of the Narwana Canal System.

Banur Canal System, another inundation canal of the River Ghaggar, which takes off from Chattbir though still working with varied efficiency, is to be transferred to SYL (Sutlej-Yamuna Link) system and remodelling of the system is in progress.

As will be seen the most of the inundation system listed above are extinct and area transferred to other systems built later. One aspect to be noted is that the engineers with aim to improve irrigation intensity and reliability of water supply, transferred the load to the River Sutlej leaving the potential of the River Ghaggar completely utilised or tapped.

2. 3. WESTERN YAMNA CANAL (WYC) SYSTEM—RIVER YAMNA

2.3.1. **Historical** : The Canal System built by Feroze Shah Tuglak had fallen into disuse by the end of the Mughal Rule. In 1817 A.D., Mr G.R. Blane of the Bengal Engineers was entrusted with the task of restoring the canal which had ceased

to flow in around 1705 A.D. It took him three years to complete the job. Soon thereafter, in 1821 A.D. Mr Blane died of malaria at Ludhiana. Due to paucity of funds, Blane did not improve the alignment of the canal adopted previously, which connected low lying areas and caused extensive water logging. The remodelled canal had its off-take near Hathni-Kund and flowed along the old creek till it crossed Pathrala and Somb torrents. No permanent headworks was built.

After famine of 1832-33, enlargement and modification of the canal system was undertaken. But as the work was executed in haste and also along the old alignment, so the benefits were not as large as expected. But even then, the financial returns from this canal rose to 13 percent net in 1847. This encouraged the administration to remedy the defects of alignment and also to construct drainage works.

In 1873, further remodelling of the canal was taken up and a permanent weir was built at Tajewala and cross-drainage works at Dadupur, for torrents of Pathrala and Somb. The above remodelling was carried out by Mr John Colvin of the Bengal Engineers, between 1875 and 1879. The Sirsa Branch of the System was constructed in 1889-95 A. D.

The canal was again remodelled in 1940-43 when irrigation was extended. In 1947, the WYC carried full supply discharge of 8050 cusecs (228 cumecs) during Kharif and 6784 cusecs (192 cumecs) during Rabi. It irrigated area of the districts of Karnal, Rohtak and Hissar (all of those now in Haryana) and GCA (Gross commanded area) of 3,156,912 acres out of which CCA (Culturable commanded area) being 2,614,144 acres. Shortages were experienced in the WYC command area during lean period as there did not exist efficient control over rivers due to 'drop-shutter' type system still in use at Tajewala weir. The annual intensity was hardly 43 percent and the canal usually suffered from very long winter closures. The water allowance was also very poor.

2.3.2. Step Taken to Remedy the Situation : In addition to poor water allowance and uncertain water supply there were certain compact blocks of area contiguous to the existing irrigation boundary and within it, which although culturable and commanded, yet did not receive irrigation water, due to short-

age of supply. To meet the demand for irrigation of the above listed areas, two pronged attack was launched after independence, in pre-five year plan phase. One was to extend flood irrigation to areas on Bhalaut Sub-Branch and olso on Sunder-Sub-Branch. Thə concept had been tried duiing pre-partition period and found successful and so was extended now. The other prong of attack was to back up the canal supply through tubewell pumping—conjuctive use of surface and ground water or augmentation scheme of Jagadhri Tubewells was taken up in which 256 deep tubewells of two cusecs capacity were installed. The contribution on this account of 512 cusecs continuous flow was consideied equivalent to 1237 cusecs of canal water flow and had a capacity factor of 0.38. (the mean flow during *Rabi* season on WYC).

Despite the two steps taken, shortages in WYC command areas still continued to be felt. Next measures taken were transferring entire area of Sirsa branch, having full supply capacity of 1794 cusecs (50.8 cumecs) to Bhakra Canal System to be fed through Narwana Branch and also transferring Distributary to the Bhakra System, sparing about 100 cusecs (2.83 cumecs). The total extra water that became available in WYC Camand after above two transfers was 1894 cusecs (53.63 cumecs), which was spread over the balance area of WYC after remodelling it at a cost of Rs. 5.94 crores.

The above measures transformed many of the non-perennial areas into perennial ones and improved the water allowance in the command area of WYC. Also many new areas came under irrigation. As a result the irrigated area increased from 804,490 acres in 1947-48 to 1,295,566 acres in 1963-64. The length of distributaries increased by 206 miles.

3.0 PRESENT DAY CANAL SYSTEM

The present day canal system mostly came into existence during the British Rule. The entry of the British in the region dates from the year 1819 A.D. when the Government of India accepted the allegiance of the Sikh Rules of the Cis-Sutlej tract, thus extending the British Rule inio the tract between the river Jumna (now spelled Yamna) and the River Sutlej. Gradually a new district of Ambala came to be organised. The portion

beyond the River Sutlej came to be annexed in March 1849 soon after tne death of Maharaja Ranjit Singh. The British Engineers inherited a net-work of inundatian canal which was functioning to different degree of efficiency. Most of the canals had got silted. So the first task of the engineers was to attend to the improvement of inundation canals and the various system tackled are reviewed river wise.

3.1 The Canal System of the River Ravi—Upper Bari Doab Canal (UBDC) System.

3.1.1. Historical : After occupation of Lahore in 1849, the British undertook the improvement of tne ancient 'Hansli'. The plan for renovation and extension of irrigation had been initiated earlier, during the Regency with the consent of the Sikh Durbar. The work was entrusted to Capt. Longdon, Lt. Anderson and Lt. Hodson, under overall control of Lt. Col. Robert Napier. Work got interrupted on account of Multan insurrection, but by then considerable data had been collected by team. After annexation in March 1849, proper permission to start work, was given to Col. Napier and he deputed Lt. Dyas to conduct systematic survey and investigations taking into considerations the data already collected. Within one working season, a complete plan of the whole 'Doab', showing topography, levels, nature of ground surface, drainage, etc, was made available by Lt. Dyas.

As a rrsult of the above information, it was decided that the old alignment of 'Hansli' be dropped as it did not have enough command and a new canal be built along a different alignment, following ridge instead of depressions. The new canal was called Bari Doab Canal in the beginning and later on when Lower Bari Doab canal (now in Pakistan) came to be built, it was renamed as Upper Bari Doab Canal (UBDG). It was to off-take from Madhopur, rim station on the river Ravi and traverse, 'Majha' tract of the Bari Doab, passing near the town of Dinanagar, Batala, Amritsar and passing down the Central Bari Doab thereafter. The canal was proposed to have outfall into the river Ravi, at a point 90 kms above the town of Multan. Lord Dalhousie, the then Governor General, satisfied himself about the feasibility of the project by visiting the proposed canal head near Modhopur in November 1851.

There was no reliable data available about the river flows, particularly the minimum flow at Madhopur, the off-take point. The first estimate made during February 1848, placed the minimum discharge at 2752 cusecs (78 cumecs) but only three year later, in December 1851, the figure was found to be lower, 2016 cusecs (57 cumecs) only. In the initial 288 kms length of the proposed canal, irrigation was to be provided and the rest of the reach was proposed to be used for navigation. The full supply discharge was fixed at 3000 cusecs (85 cumecs).

During construction it was decided to curtail the scope of the project by removing the navigation aspect mainly and the canal was stopped short of Chhanga-Manga (place near Lahore, now in Pakistan), about 160 kms short of its previous out-fall point. The canal was finally opened in 1859 and irrigation from it commenced in 1861. At first distributary system was not provided and the irrigation was done by open flooding by cutting the banks of the main canal. Permanent Headwork also did not exist then at the off-take point.

The work of construction of a permanent headworks at Madhopur was taken up in 1868, but before the headworks could be commisioned, it got seriously damaged during floods. The whole scheme was revised in 1874 and its scope was increased to provide for a properly designed distributary system. An interesting work connected with the construction of the main canal was diversion of the Chakki Torrent, which originally flowed into the River Ravi and intercepted the canal alignment. In order to obviate construction of a large cross-drainage works on the canal, it was decided to divert the torrent into river Beas by cutting through the water-shed between the River Ravi and the River Beas. The scheme involved cutting through a hill about 60 m high. The torrent now takes a sharp turn towards left, near the town of Pathankot and flows through an enormous artificial gorge to join the river Beas lower down.

As the country slope in the head reach of UBDC was very steep, so in its first 30 miles large number of rapids were provided to keep excavation within permissible limits.

The revised scheme was completed in the year 1879 at a cost of Rs. 2.76 crores. In the year 1947, the area benefitted was 37,750 acres and its full supply during Kharif was 6900 cusecs and 5700 cusecs during Rabi and the gross commanded area (GCA) amounted to 1564,000 acres out of which cultu able commandable area (CCA) was 1456,000 acres. The area which went over to East Punjab was GCA 856,544 acres and CCA 789,000 acres.

3.1.2. Effect of Partition on the UBDC Command : The Radcliffe line not only divided Punjab into East Punjab and West Punjab but also led to partition of the command area of the UBDC system. The part of the command which went over to West Punjab (Pakistan) came to be named as Central Bari Doab Canal (CBDC) and comprised of the area lying on the main Branch Lower below R.D. 22400 ft. (the last control point) and its Khalra Distributary and Bucchar Khanna Distributory; Lahore Branch below R.D, 172800 ft. (last control point) and its Pull Distributary and Kohali Distributary. The supply to the CBDC System amounted to 1710 cusecs from the main Branch lower and 651 cusecs from the Lahore Branch, totaling 2361 cusecs at the border at two control points.

3.1.2.1. *Excavation of new distributaries in the UBDC System* ; Two new distributaries of Kasur and Sabraon Branches were built in pre-plan period (upto 31.3.1951). Also Chheharta Minor of Amritsar distributary and Rajasansi Distributary itself were constructed during this phase. Steps were taken to extend irrigation to arid areas of Jandiala and Gurdaspur Divisions of the UBDC circle. Other channels added to the list were, Trimminwal minor, Chogawan-Wagha minor, Ajnala Distributary, Kalanaur Distributary, Saidoke Minor and Mohsaum Minor. The attention of the East Punjab was focussed to extend irrigation to the maximum extent possible, keeping in view, the obligations of May 1948 Inter-Dominion Stand Still Agreement.

Big chunks of area located inside and just outside the canal command boundary were searched and were taken up for bringing under canal irrigation even though to start with under non-perennial i.e. supplying water during kharif supplies which

were above the requirement of the CBDC system of Pakistan and already irrigated areas of UBDC. Funds for the works were obtained under The Grow More Food Programme and 'Minor Irrigation Schemes'. A large number of non-perennial, listed in the beginning were excavated and this effort increased the length of channels from 375 miles in 1947 to 933 miles in 1957. This added a solid block of 435,000 acres of new areas to the area receiving irrigation. As a result of these efforts remodelling of the system became necessary. Remodelling was carried out at a cost of Rs. 56.34 lakhs. As a result of remodelling the full supply of UBDC at head rose to 8974 cusecs during Kharif compared to about 6900 cusecs drawn during Kharif of 1947. The intensity of irrigation rose to 87 percent.

3.1.2.2. *Remodelling of UBDC Main Line - Salampur Feeder and Head Regulator* : As discussed above, remodelling had become necessary due to increase of non-perennial irrigation in the UBDC command. The remodelling involved the following measures.

The capacity of the Salampur Feeder was raised from 2000 cusecs to 4000 cusecs.

As the M-B Link (Madhupur-Beas Link) utilised the first two miles of the head reach of the UBDC Main-line, its capacity rose to 17000 cusecs from the previous authorised full supply discharge of 5000 cusecs. The increased capacity was obtained partly by deepening the bed and partly by raising the full supply by 3 feet. The velocities obtained were of the order of 12 ft/sec. and consequently grouted stone pilch was provided on sides of the channel.

An additional Head Regulator capable of diverting 15,000 cusecs was taken up in March 1954 and completed in August 1954. This regulator has eleven bays of 20 feet width each. Depth of excavation amounted to about 35 feet out of which 25 feet was below the ground-water table. The structure involved a pit 350 feet x 400 ft at base and height of 44 feet. Its floor thickness was 3.5 feet and was reinforced concrete raft involving placement of about 10.5 lakh cubic foot of concrete (including stone-masonry). All this was done in just five months (March to August). In view of the urgent need,

the work was started at the commencement of the flood season inspite of great risk involved and pushed through during the flood season.

3.1.2.3. *Remodelling of the old Head Regulator of UBDC*: The old head regulator of UBDC was last remodelled during 1932-33 when counter balanced gates were provided. In 1945, the capacity of the regulator was fixed at 6900 cusecs. As a result of efforts made to increase irrigation during pre-plan period (upto 31.3.1951) the peak requirements of UBDC had risen to 8974 cusecs and subsequently it rose further on construction of additional regulator of 15000 cusecs capacity discussed above. To match the above, the capaciiy of the head regulator of the Salampur Feeder was increased from 2000 cusecs to 4000 cusecs which was accomplished during the period of March 1954 to June 1954. The capacity of the old head regulator was increased by suitable remodelling during the same period i.e. March 1954 to June 1954.

3.1.3. Silting Problem Experienced in UBDC : After partition, efforts were made to increase flow in the UBDC, to extend irrigation to those areas in the command or those lying on its fringe, particularly during summer season. This led to increased silt entry into the canal resulting in excessive silting in upper reaches of UBDC.

Silting Tank : To combat silting problem, use of silting tank was tried around 1950. Silting tanks were constructed alongside of the UBDC Main Line and through such tanks either the whole or part supplies were routed and silt deposition was induced. However, it was found that the silt deposition occurred near the inlet mainly and the whole procedure was found to be expensive and the results achieved did not commensurate with the cost involved. So this technique of silting tank was discarded and problem persisted and the situation aggravated. Even the newly built M-B (Madhopur Beas) Link was found to be getting badly silted. The reach R.D. 60,000 (ft) to R.D. 77,000 (ft) of the UBDC had silt deposits of 8 feet in the year 1951, whereas the normal full supply depth was about 12 feet. This needed raising of the canal banks and also bridges where possible.

At other bridges and falls drowing was experienced. All this made the operation of the canal very difficult.

Silt Ejectors : At the advice of the Irrigation & Power Research Institute, Amritsar, construction of a series of Silt Ejectors in the affected reach was taken up in 1953. Silt Ejectors were built at RD 72,700 (ft) and RD 134,000 (ft) of the UBDC Main Line to provide relief to the reach RD 100,000 (ft) to RD 150,000 (ft). In the beginning properly designed outfalls were not constructed and these structures did not perform to the expected efficiency. After a few years, when the outfalls with proper slope were constructed, their working improved aud in a few years bed got lowered to the design bed level.

At the off-take point of the M-B Link from the UBDC Main Line, RD 11,000 (ft) was built in record time of 14 days in April 1957 aud and its outfall was in the M-B Link, where the discharge got spread and silt deposits appeared. A separate outfall channel about one mile long was provided, which improved its working.

A silt/shingle ejector was built at RD 3500 (ft.) of the Salampur Feeder also, which was acting as supplementary channel carrying additional supplies. (The capacity of the Salampur Feeder was increased from 2000 cusecs to 4000 cusecs). Its working was found to depend upon the state of outfall channel. It worked satisfactory so long as outfall was in satisfactory state but when the outfall channel got silted or damaged, its efficiency dropped. The lining of approach channel upstream did not result in improvement of the working of the ejector.

The series of silt ejectors remedied the situation when proper outfalls were constructed.

3.1.4. October 1955 and Damage to Madhopur Weir : During October 1955, an unprecedented rains and consequential high flood occurred in the River Ravi which crossed 6.0 lakh cusecs mark. There was widespread damage to works located upstream of the Madhopur Weir, such as Dhanna Weir,

Kashmir Canal, guide bunds, etc. in addition to damage to shutter-operated Madhopur weir. Remodelling of the weir into a barrage with gates and gearing was already being contemplated as essential in view of increased withdrawls from the River Ravi. The floods experienced during October 3-6, 1955 which caused serious damage to the training works and existing works at Madhopur, hastened decision about the same.

A survey of the extent of damage when assessed revealed that Rs. 28 lakhs would be needed to carry out repairs to the damaged works so as to restore status quo ante. Cost of building a barrage instead was placed at Rs. 102 lakhs. Therefore, it was considered that it would be better to build a barrage instead of effecting repairs thus saving Rs. 28 lakhs needed for repairs. But main hurdle was that if the barrage was not ready before flood season of 1956, feeding of canal system would be difficult as no repairs would have been carried out to training works. The previous experience with construction of similar works had been that atleast two working seasons were needed.

However, the Punjab irrigation decided to take a daring step and go ahed to undertake construction of the 'Barrage' in one season.

3.1.5 Construction of Barrage : The Madhopur Barrage was consisting of 28 bays of sixty foot span and two sets of under-sluices, each having 12 bays of 20 feet each on the left. Two spans of 60 feet on right were used as undersluice by keeping their crest lower. Additional under sluices on left was projected 400 feet upstream of the gate line of the existing undersluice by two 400 feet long divide walls on either side. This was done to extend the action of undersluices to the new head-regulator built upstream of the old head-regulator for M.B. Link discharge. A fish-ladder and rafting bay as existed in the original design of the weir were retained.

The work was indeed completed in one season, except installation of set of gates. The work executed has been discussed briefly next.

On account of existence of a set of undersluices constructed and remodelled during the year 1917 and 1918 and

existence of an open weir, the choice of the site was restricted. It was decided to make best possible use of the existing structure (weir) and so the same alignment as in the case of weir, was adopted except for the advanced set undersluice which was projected 400 feet upstream.

The design and drawing of new works were prepared and indicated that 138 lakh c.ft. of excavation involving boulder and shingle would be involved and also placement of 32 lakh c.ft. of concrete and stone masonry of 11.5 lakh c.ft. The quantity of water which would have to be pumped would be 30 cusecs. Daily progress required to be achieved to complete the work within the scheduled time, would have to be 45,000 ft. concrete.

The maximum flood handling capacity of the barrage was fixed at 6.25 lakh cusecs. However, the design was checked to be safe to handle transient flood of 7.5 lakh cusecs. Waterway (net) provided was 2300 feet and overall waterway 2663.25 which matched the road bridge built by CWPD in 1948.

The pond level was fixed at EI 1143 (ft). Regulator was designed to act as submerged orifice with crest level at EI.1136.5, the required discharge could be passed. The crest level of old undersluices was at EI-1129.5 and was retained. The crest level of the weir varied from EI. 1136 on left to EI. 1138.5 on the right. It was considered appropriate to fix the crest of the advanced undersluice at EI.1136. The crest of the barrage was fixed at EI. 1137 and the effect of the cross-slope in the river was provided for by varying depth of gates. The capacity of the various components fixed was :

Component	Discharge capacity (cusecs)
Existing undersluices Left Packet	94,700
Advanced undersluice	97,500
Barrage Bays	3,96,000
Right side undersluice bays	40,000
	6,28,200 cusecs

Free board was fixed for the flood of 750,000 cusecs and the barrage bays were designed for concentration of flood up to 20 percent, but undersluices were designed to work without any concentration of flow. For working design of curtain walls etc. slit factor value of 10 was used.

Though the floor thickness was worked on the basis of Khosla Theory, but in the design adopted the thickness adopted was kept 50% of the design thickness. This was done as the strata encountered was considered to be compacted gravel and sand, with fair distribution of boulders instead of sandy formation as considered in the Khosla Theory.

3.1.5.1. *Kashmir Canal :* With decision to build a barrage instead of carrying out repairs, it became necessary to shift the location of the off-take point of Kashmir Canal downstream to the right flank of the proposed barrage and a small area which was to be got out of irrigation due to loss in command due to this shift of about 5 kms, was provided with lift irrigation.

The area irrigated by Chirs and 'Khuls' originally off-taking from the right side of the River Ravi and which would have gone 'dry' due to construction of a barrage and the increased withdrawls to the tune of 23,000 cusecs (21000 cusecs from the left bank including M-B link requirements and 2000 cusecs from the right bank) were also to be met from the right bank regulator, whose capacity was fixed at 2000 cusecs. The head regulator built has five bays of 20 feet each. To have an effective control over silt movement, the last two bays of the barrage on the right were designed to act as undersluices with their crest depressed. With the pond level of El-1143 (ft) in the left pocket and existence of a cross slope 1 in 500 in the river from right to left, pond level required in front of Kashmir canal Head-Regulator was El. 1147.0. But it was considered by the designers that after the construction of a barrage, the 'pond' conditions would get stabilised and the cross slope would vanish. Consequently the pond level for designing of Kashmir canal was fixed at El. 1143.5 (ft), only 0.5 ft higher than that in front of UBDC Head Regulator. The full supply in the canal was kept as El-1142.0 ft and this provided a working head of 1-5 feet.

3.1.6. Conversion of Non-perennial Areas into Perennial : In 1968, it was decided that the point of delivery of supplies to Centre Bari Doab areas of Pakistan be shifted to Madhopur works and supplies routed through the river instead of delivery points near Wagah border on the Lahore branch and UBDC Main line lower. The position was examined by the Punjab Irrigation Engineers and it was found that there would be a saving to the extent of 295 cusecs in the UBDC system on account of seepage losses (calculated at the rate of 12.5 percent of 2361 cusecs required to be delivered). This saving was utilised and steps taken to convert a number of channels built as non-parennial in the post-partition period, into perennial.

The first to be converted were the Dhianpur Distributary and Kakar minor of Pull Distributary, which utilised 115 cusecs and this was effected through a gazettee notification dated May 16, 1968, which read as follows :

'It is hereby notified that Dhianpur Distributary and Kakar Minor, taking off at RD 76900 R from Main Branch upper of UBDC, are converted from non-perennial into perennial with immediate effect'.

The second batch taken up was on July 12, 1968, when it was decided to convert Fathegarh Ditributary off-taking from R.D. 123,653 of Main Branch upper, from non-perennial into a perennial channel with immediate effect.

The thrid notification dated Nov. 11, 1968, converted Riarkee Distributary off-taking from Sabraon Branch R.D. 34010-L, from non-perennial into perennial channel.

The above conversions were adjusted against savings of 295 cusecs. On Feb. 19, 1969, it was decided that Pakistan's share to be released below Madhopur Barrage may be reduced to 1800 cusecs (instead of 2361 cusecs released earlier) as supplies from the Mangla Dam had become available through replacement links built under Indus-Basin Project as a part of the Indus Water Treaty. This led to further conversion. Same year, on August 23-28, 1969 during the meeting of the Permanent Indus Commission it was decided that India may not release any water at Madhopur for Pakistan to cover CBDC supplies

during the period of September 21, 1969 to Feb. 20, 1970. This released more supplies for use in UBDC System and conversion of a large number of non-perennial channels into perennial. The channels covered were :

1. Sarna Distributary
2. Awankha Distributary
3. Gulpur Distributary
4. Bhatto Distributary
5. Nanu Nangal Distributary
6. Ghazikot Distributary
7. Babehali Distributary
8. Fateh Nangal Distributary
9. Rania Distributary
10. Kot Karm Chand Distributary
11. Kunjab Distributary
12. Dhariwal Distributary
13. Kotla Distributary
14. Jandiala Distributary
15. Talewan Distributary
16. Dhardge Distributary
17. Adliwal Distributary
18. Wadala Distributary
19. Ghaggan Bhana Distributary
20. Bhinder Distributary
21. Nony Distributary

This marked an important mile stone in the development of irrigation in UBDC tract.

3.1.7. Madhopur—Beas Link Project : This link was built during 1st Five Year Plan period (April 1951 to March 1956) at a cost of Rs. 246 lakhs. The work involved convertion/remodelling of the Madhopur weir into barrage, to enable better control of river supplies, construction of a new head regulator, remodelling of head reach of the UBDC main line and excavation of the link. All the items of work except last, have been discussed earlier.

Need for the Link : Kharif irrigation had been provided on the Eastern canal on a fairly large scale and this was met

from surplus supplies available in the River Sutlej over which the Sutlej Valley Canal (SVC) system of Pakistan had no right. But when supplies began to be diverted into Bhakra Canal System, it was feared that the areas on Eastern Canal would suffer and there was danger of benefit extended vanishing unless the surplus Ravi water could be brought to Harike, through a link, which came to be named as Madhopur-Beas Link.

Construction of M-B Link : Construction of a 13 miles long M-B link channel was started in November 1954. The capacity of the link was fixed at 10,000 cusecs. The excavated channel was to deliver the Ravi supplies taken over at R.D. 11000 of the main line to the River Beas via Chakki Torrent. The channel excavated was 140 feet wide and 8 feet deep and at some places involved excavation to the tune of 40-50 feet of gravel-boulder slide. Number of drainage channels were intercepted for which cross-drainage works (in lets) had to be provided. As the country side slope was very steep so seven falls, of drop varying between 5-10 feet, were constructed. The construction work was completed in June 1955 and for the first time supplies were let in the M-B Link in September 1955 and irrigation needs of the Eastern canal were met without any interruption.

3.1.8. Construction of UBDC Hydel Channel : In order to utilise the hydel power potential available in the reach of the UBDC Main Line upto RD 72,000 the construction of the UBDC Hydel channel stage I was undertaken in mid 1960's. It involved construction of a hydel channel, which had an independent alignment for most of the reach except part of the Salampur Feeder and three power houses where a drop of 50 feet each was to be utilised through 15 MW units, total capacity of three power houses being 45 MW. The hydel channel in stage I had full supply capacity of 3600 cusecs and it was 21 kms long and dropped supplies into the UBDC Main at RD 72,000. The three power houses are located at RD 13,500, RD 25,000 and RD 40,000. The last power house was commissioned on April 13, 1973.

To have greater control over silt entering, not only the silt ejector at 3500 was remodelled but also a new silt ejector was

provided at RD 10, 800 with properly designed outfall channel. So as to conserve water re-source, the outfall channel dropped supplies into the UBDC Mainline, instead of dropping it into the river Ravi because in the latter case the water would have flown waste as India had no control point built on the river Ravi below Madhopur.

The working of this silt ejector was checked by tests on prototype and it was found that there was conformity between model prediction and prototype behaviour. An efficiency of 64 percent was obtained.

3.1.9. Thein Dam : The proposed Thein Dam is located across the river Ravi near the village Thein, latitude 30°-26-30 N and longitude of 75°-43′-30″ and would be 160 m (525 ft) high earth-core-gravel shell dam, with upstream inclined core. The site is about 12 miles upstream of the Madhopur head works. The foundation strata consists of alternate bands of sandstone and clay shale dipping at an angle of 50° to 70° in the downstream directon. The depth of over burden material varies from 2 ft to 5 ft at higher levels and 4 ft to 7.5 feet at lower levels, in right abutment. In the left abutment the overburden is relatively less. In the bed over burden varies between 46 feet and 50 ft. The approved alignment of the dam axis is askew to the strike of the bands by 45°. The sandrock bands are generally coarse to medium grained, micacious at places and contain occasional fragments of clay-shale/silt stone set in sandy matrix. These bands are of varying hardness. The clay stone/silt stone bands though found compact and hard when freshly exposed but develop dehydration cracks on getting exposed to weather or on drying.

For diversion of the river four diversion tunnels of 40 feet diameter are being excavated and all the tunnels are located in the left abutment. After serving the function of diversion, two of the right side tunnels will be converted to serve as penstock to deliver water to the power house units which will have 4 units of 150 MW each. Other two tunnels will be converted into irrigation outlets to release supplies when power house is not working. Layout and design of tunnels, intake works is quite similar to that of the Pong Dam at Talwara on the River Beas previously. Each tunnel is expected to handle 75,000 cusecs of flow during diversion stage.

It may be mentioned that during September 1988 floods, when the flood over-tapped the ring bund, the tunnels got filled with debris and musk. There were failures of rock near portal on two of the tunnels. Valuable machinery got damaged. Even the power house pit got flooded and machinery submerged and damaged.

As regards spillway, it will be located on the left abutment and two tier arrangement is being utilised in which surplus energy will be dissipated in two stilling basins working in cascade.

Looking back, the proposal to build a storage on the River Ravi formed a part of works conceived as a part of the Indus-Water Treaty of 1960 which gave exclusive right to India to utilise entire flow of the three eastern rivers, Sutlej, Beas and Ravi. In the project design report prepared in mid 1960's a straight gravity concrete dam was proposed. The project design and site conditions were examined by Dr F. A. Nickel, an expert from U.S.A. who opined that site would be more suitable for an earth-dam instead of rigid structure of concrete dam due to seismic status of the site. So the earth dam came to be adopted.

Shahpur Kandi barrage is located below Thein Dam and is expected to serve similar function as Nangal Dam serves in relation to Bhakra Dam to even out releases made out at Thein Dam in the interest of power. From the Shapur-Kandi Barrage two channels will off-take, Ravi Canal from the right bank which will cover areas at present being irrigated by Kashmir canal off-taking from Madhopur. From the left bank a hydel channel will off-take which will drop water above the Madhopur Barrage and utilise a drop of about 50 feet available for power generation.

The boundary between the states of Punjab and Jammu Kashmir runs along the centre of the river, so right bank works are in J & K. Only about 800 acres of the area to get sub-merged lay in Himachal Pardesh and rest in Punjab and Jammu & Kashmir. There were some difficulty in acquisition of area in Jammu & Kashmir for the Thein Dam due to its special status and this resulted in delay. Punjab offered concessions to Jammu & Kashmir in the form of charging only nominal cost of the Shahpur Kandi project which was to benefit Jammu

& Kashmir as regards irrigation as canal off-taking from higher level than Madhopur had greater and better command.

Thein Dam (Ranjit Sagar Dam) - Salient features

This dam save 2 MAF (2500 Mm^3) water which otherwise goes waste below Madhopur headworks every year. The dam lies in the lower Shivalik range of the Himalayas and is located near village Thein about 15 miles upstream of Madhopur Head Works in Gurdaspur district of Punjab. The dam site is about 18.75 miles from Pathankot and about 325 miles north-west of Delhi. The inter-state boundry between Punjab and Jammu & Kashmir passes along the centre line of the river, thus the right abutment of the dam will be in J & K State and the left abutment in Punjab.

The dam will be 525 feet (160 m) high, an earth core cum gravel shel structure. At top it will span between abutment by a length 1855 ft. The width of the dam at base will be 270 feet.

Storage reservoir which will be created has been named after Maharaja Ranjit Singh as Ranjit Sagar and will extend 13.75 miles upstream with a maximum width of 3.125 miles. Gross storage will be 2.659 MAF (3680 Mm^3) and live storage 1.55 MAF.

For diversion of the river, four tunnels are being constructed which will have finished diameter of 40 feet and total length of over 10,000 feet. Each tunnel will be able to pass during diversion stage a discharge of 75,000 cusecs.

After serving the function of diversion of the river, two of the four tunnels will be utilised as irrigation outlets and the other two to feed four units of 150 MW each of the power house. Francis type of turbines for maximum net head of 405 feet and minimum head of 246 feet are being used. A two tier concrete spillway is proposed to be located on the left abutment and will have water way (clear) of 357.6 ft and crest level at El.1679.76 ft and will be capable of passing 7.73 lakh cusecs of flood.

The project is expected to be completed by the year 1995. It will involve placement of 20 million cyds of fill and 1.4

million cyds of concrete and would require 0.35 million tons of cement and 0.16 million tons of steel.

3.2. Shah Nehar Canal System—Offtaking from the River Beas : As seen previously, an inundation canal was built by private enterprise in the year 1744 A.D. and it off-took from the river Beas from Rey Head near the village Hajipur-Mukerian. It got soon silted up and by the time of advent of the British rule, practically no irrigation was carried from this channel. Some local zamindars under the leadership of Chaudhry Dhaia Singh cleared the canal at their own cost and extended irrigation up to the town of Mukerian in 1846-48. But by the year 1869, the condition of the canal deteriorated again.

Mr Perkins, the then Deputy Commissioner of the area intervened and helped in its silt clearance. For ensuring a better management an agreement was reached with the users and this mode of management came in force from March 1871 onwards. Under the agreement, the funds for repairs and maintenance were collected from the farmers who utilised the canal water and its management was entrusted to a paid employee and the first manager was Chaudry Khark Singh. This system remained in force till the first settlement of the area in 1890 when the Punjab Government decided to take over the management of the canal and acquired all the rights of the shareholders. This mode remained in force till 1949-50 when it was passed to the Punjab Irrigation Department.

The Punjab Irrigation Department placed the operation of the Shah-Nehar System under control of the Executive Engineer, Madhopur Division of the Upper Bari Doab canal circle. This system remained operative till supplies began storing in the Beas Dam at Pong.

With the storing of supplies in the Beas Dam, the working of the Shah Nehar system got disrupted. So it was decided to build a weir at location about 8 kms below Pong and opposite Talwara Township, on the River Beas, so that supplies to Shah Nehar System could be ensured. The cost of the control structure (about Rs 1.8 crores) was partly met by the Bhakhra Beas Management Board.

Later on it was decided that instead of a weir a barrage be built which should also feed the Mukerian Hydel Channel,

with four power houses having totalled installed capacity of 164 MW and the Shah Nehar Feeder to off-take from the Mukerian Hydel Channel below Power House I, thus taking advantage of power generation of the Shah Nehar Feeder flows. Though on the previous phase water allowances from an inundation system were high but unreliable, so the users accepted lower water allowances, compatible with the rest of the UBDC areas, as supplies became assured.

Working of the System :

During the period the system was controlled by the District Board, the area irrigated seldom exceeded 15,000 acres. When the system was taken over by the Punjab Irrigation, funds were obtained under 'Grow-More Food Programme' and system was improved. As a result, irrigation rose to 47,000 acres. The expenditure on remodelling and improvement amounted to Rs 12.38 lakhs. In 1963-64, the gross commanded area (GCA) was recorded as 63996 acres out of which culturable commanded area (CCA) was 51,000 acres. The further development of irrigation is proposed to be covered under Plan-Scheme, under head Extension and Improvement of Shah Nehar System' with the targeted figure of 1,68,844 acres.

3.3. Sirhind Canal System—off taking from the River Sutlej from Rupar Headwork, Rupar

3.3.1. Historical : The idea of utilising waters of the river Sutlej for irrigation of the vast tract, lying between the Western Yumna Canal and the River Sutlej, dates back to the year 1840, when Capt. William Baker, (who later became Major General and was known as Major General (Sir) William Baker, after a thorough study of the region, prepared a project for the purpose. Capt. Baker being a student of Thompson College Roorkee was better acquainted with the local conditions. Though Baker's Project came up for consideration of the Government on many occasions, but due to one reason or the other, it was not approved. On this project the canal was to cover many princely states in addition to the British Punjab, so there were numerous problems of sharing of cost, benefits, etc. The States involved were those of Patiala, Nabha, Jind, Faridkot, Kalsia and Malerkotla.

In 1861 a proposal was received from the Maharaja of Patiala, for taking up the Baker's Project and the ruler of Patiala State offered to bear the cost of survey investigation and project preparation, if the British would provide personnel for the work. It was also agreed that Patiala State would bear the cost of works falling in the Patiala State.

As the large portion of the proposed canal off-taking from the River Sutlej was to traverse Patiala State, so the above offer gave a good phillip to starting of the project planning on sound lines. The offer of Maharaja Patiala was accepted straightway by the British Government and Capt. Crofton, who had many years of experience on the western Yumna Canal and the UBDC, in carrying out surveys etc. was deputed for the purpose. Capt. Croftan prepared a 'Prelimiary Report' and submitted the same to the Punjab Government in the year 1862. It provided for a canal of 4000 cusecs capacity off-taking from the River Sutlej and irrigating areas of both the princely States and the British Punjab.

The above report initiated considerable discussions in concerned quarters regarding the alignment to be followed and also regarding the extent of areas to be irrigated in the British Punjab and the Princely States. When the Report came up before the Director of Canals, Punjab P.W.D. Irrigation Department, Capt. J. H. Dyas, for decision, he took most dispassionate view on the object and observed :-

> "Looking as an engineer merely at the question of the employment of the water of any river, and assuming that no special reason exists for irrigating any particular tract, I am of the opinion that the best line for a canal is that from which the largest extent of country can be irrigated at the smallest cost, irrespective of the name or nature of existing government of the country in question. If a large extent of Patiala than of British territory can be irrigated from the Sutlej with the same quantity of water, at a smaller cost, then it would appear to me that the Sutlej was intended for irrigation of Patiala and I would run the canal accordingly. *Governments are always likely to change but a properly made canal will endure for centuries if not for all times and every Government is equally interested in its maintenance*". (extract from memorandum dated Oct. 22, 1862).

The Scheme framed by Capt. Crofton was duly forwarded by the Punjab Government to Government of India in late spring of 1868, even though it was considered that the scheme was not very definite on question of costs and amortization of the proposed cost. The scheme was accepted and the Government of India authorised the Punjab Government to proceed with more exact designs and estimates and also with the land acquisition. Authority was also given to the Punjab Government, to start negotiations with the princely states through whose territories the canal was to flow and also to irrigate the areas. Later that year, the Government of India approved the commencement of the construction of the project in anticipation of the formal sanction from the Secretary of State for India London, even though exact estimates were not yet available. When the exact estimate for the project became available, it was found that it was likely to cost Rs. 87.53 lakhs and the return from the project would be around 10 per cent of the capital cost.

A treaty was signed with the Patiala State in 1869 and work on the project was commenced that year. The scheme underwent some changes, until it took final shape in 1870, when the project estimates and design of the headworks were sanctioned. The cost rose to Rs 170 lakhs. This project was to be financed from public loan fund and it was to be constructed solely by the government agency, to irrigate areas lying in both the British Punjab and the Princely States of Patiala, Nabha, Jind, Faridkot, Kalsia and Malerkotla, without any consideration of political boundaries. This was done under a policy decision taken by the Government of India in 1868.

In the year 1873, when the work was initiated, an agreement was drawn up regarding the use of water of the canal between the principal parties and about the sharing of the cost. The cost of common works and their annual maintenance and also the canal water supplies available were shared by the British Punjab and princely states in the ratio of 64:36 percent.

3.3.2. **Construction phase :** Though the work of construction of Rupar Headworks and the Sirhind Canal was undertaken in the year 1873 but the real start on the construction of the headworks was made in the winter of the year 1874 and was done on Nov. 24, 1882.

The work of this project was faced with many problems. Engineers engaged on the design and construction had no previous case to guide as up to that time (year 1869) no weir had been built any where in the Indus Basin, not even at Madhopur for UBDC even though the canal had been built earlier but it was without a regular weir. The works built by Sir Arthur Cotton, between 1836 and 1865 in Dean Peninsula were founded on rock and as such did not provide any guidance for work to be built at Rupar on pervious gravel foundations.

3.3.3. Site Selected for weir : The site for the weir on the river Sutlej chosen was such that river flowed there in a single channel between high walls, well defined banks with maximum flood surface of El-762 (ft). The bed of the river at the site comprised of shingle and boulders. The site provided a favourable condition for obtanining the whole river supplies during cold weather, with a weir of minimum width of 2400 feet. The weir crest was placed about 6 feet above the normal river bed level. Twelve number undersluice bays each of 20 feet wide were provided on the left side of the weir. A regulator having 13 bays of 21 feet was provided and the weir axis and that of the head-regulator was kept as 75°. An arrangement of movable (drop) shutters was provided. Over 330 ft length of weir on the right side, a masonry bridge was provided. The undersluices were fitted with hoisting arrangement, operated from the masonry bridge provided. Also a lock channel, placed about 550 ft upstream of the head-regulator was provided for navigation traffic from upstream of the river into the Sirhind canal. The entire length of the weir was divided into six bays by piers which carried standard supporting ropeway which provided access to the right bank during floods.

The works constructed were in stone masonry and sand stone was obtained from Nalagarh Quarry about 14 miles from Rupar. Mortar used was kankar-lime-surkhi mortar and to obtain surkhi, bricks were taken from ruins of Sirhind as those ruins provided a ready stock of well burnt bricks. Kankar lime was obtained by burning 'Kankar' obtained from quarries of Patarhari village located a few miles from Rupar. As regards labour, a novel experiment to employ 'convict labour' was made on a fairly large scale. Three temporary jails were

built for housing 2500 convicts but the maximum strength of convict labour employed never exceeded 1800, rather varied between 1400 and 1800 persons. Their experiment was found to be very useful, as the presence of such a large force, which could be deployed on any urgent work any where and also exercised a stabilizing factor for the rates to be paid to free labour.

During the construction stage of the project, a workshop was established at Rupar, which not only provided facilities for maintenance and repairs of construction machinery but also provided foundary unit. The gates and gearing for the head-works and other structures for the canal were manufactured in this workshop.

A railway line covering a distance of 54 miles, from Doraha to Nalagarh quarries was also laid to carry stones. Shortly after completion of the canal, in 1884-85 the railway line was dismantled.

The Sirhind canal in its head reach passed through heavy cutting upto RD 49,000 (ft) and the maximum depth of cutting was about 26 feet. In the next reach, RD 49,000 to RD 55,000, the canal passes throuh a natural depression and so involved high filling. In the reach RD 55,000 to RD 76,000 the canal is in the balanced cut and fill section and is in slight cutting from RD 76,000 to RD 123,000. Thereafter upto RD 130,00 the canal has got full supply nearly at ground level.

Two major torrents of Budhki and Siswan cross these Sirhind canal in its head reach and for these stone-masonry arch type super-passages had been provided.

The whole work was completed at a cost of Rs 407 lakhs. The idea of constructing a weir across the entire width of the river was clear to the engineers but there was no direct pre-cedent or parallel of such work available. So the Rupar weir was certainly a bold experiment on a very large scale. Under such situation it is not surprising that some mistakes were made.

3.3.4. Performance of the Rupar weir and the Sirhind Canal : The design of the headworks was found to be defective as much heavy slit entered the canal resulting in heavy 'shoaling' which

resulted in decreases of its carrying capacity. Huge amount of money had to be spent on dredging the canal bed year after year. Situation is best described in the words of Mr Montague, the then Chief Engineer Irrigation Works, Punjab as below :

> "The canal was opened in 1882 and in view of the care which the designers and contractors had taken to induce worst possible silting conditions, it is not surprising that heavy silt and all problems arising therefrom were experienced immediately. For next 10 years, silt continued to build up both in the pocket and in the canal, thus radically reducing the capacity of the canal. In mid 1890's it appeared that canal might silt up completely and it looked very much as if the silt trouble had nearly killed the Sirhind canal and the canal might have to be abandoned."

3.3.4.1 *Causes of silting* : The main causes which led to excessive silting were :

—Inadequate gradient of Sirhind Canal. In the case of UBDC the engineers had provided a very steep gradient of 1 in 750 and it led to scouring or erosion. But the designers of Sirhind canal provided a very flat slope of 1 in 8000.

—Inadequate size of the pocket to accommodate silt. The depth of the pocket was kept as 2 feet which was found to be too small to accommodate silt.

The situation by the end of 1903 became very severe and its capacity dropped to 8165 cusecs and area irrigated dropped to 11.7 lakh acres.

3.3.5. Remodelling of Rupar Headworks in 1915 : When it appeared that the silting trouble may lead to abandonment of the Sirhind canal, Col. Ottley, the then Chief Engineer (Irrigation) took decision to modify the headworks through remodelling, which was completed in 1915.

During remodelling, the weir was filled with falling type shutters about 6.0 feet high and the water way of the head regulator was increased permitting the raising of crest of the regulator bays. A divide wall about 1000 feet long was also

constructed to isolate the pocket from the weir bays. This introduced a still pond method of river regulation, for the first time and this mode is still very much favoured though with some modifications compared to that adopted at Rupar. Steps were taken to improve approved conditions of the river to the Sirhind Canal Regulator by providing series of spurs. The effort involved in getting remodelling proposal through the various authorities can best be described in the words of Nicholson, the then Chief Engineer Irrigation Works (Punjab) :-

> "Rupar to my way of thinking is the first of the old headworks in the province (Punjab). It was constructed and remodelled when engineering principles were given more consideration than financial advisers."

During remodelling the original sluice gates were also replaced by counter-balanced gates which were designed by M/s Ransome and Rapier of Ipswich (England). The new gates could be raised or lowered in much shorter time than before, so provided a better control over the river during floods.

As a result of remodelling the capacity of the canal was raised to 9535 cusecs, and gross area irrigated became 23.7 lakhs acres. The cost of remodelling amounted to Rs. 447 lakhs.

3.3.5.1. *Performance after remodelling of* 1913 : The project after remodelling proved to be very profitable and return amounted to 26.7 percent.

3.3.5.2. *Picture on* 15 *August*, 1947 *on the Sirhind Canal.* The Sirhind Canal built at a cost of Rs. 4.51 crores in 1882 remodelled at a cost of Rs. 4.47 crores in 1915 had authorised full supply, on August 15, 1947 of 9047 cusecs during Kharif and 8438 cusecs during Rabi. The canal served a GCA of 44.54 lakh acres of the districts of Ludhiana, Ferozepur, Hissar, Bathinda and Patiala, out of which CCA amounted 37.24 lakh acres. The river feeding the canal had ample supplies during summer but during winter sometimes its supplies dropped as low as 3030 cusecs so the various branches of the system were run in rotation. Irrigation intensities and water allowance were very low and supplies were for lesser period in winter.

3.3.6. Efforts in post-partition period to improve conditions in the Sirhind Canal command : Because there were vast tracts of land within the command and just out side the command demanding irrigation supplies and on account of low water allowance and intensity of irrigation, these aspects came to be highlighted when planning was being done for Bhakra Canal System. The supplies in the Sirhind Canal command, adjacent to the proposed new areas of the Bhakra Canal System were to receive far less water, so it was decided to improve conditions on the Sirhind Canal command also. It was decided to plan irrigation on the pattern of the Bhakra Canal System and undertake remodelling of the Sirhind canal system if found necessary.

Scattered un-irrigated areas lying within its irrigation boundray were searched and considered for providing irrigation. The arid tail area of 1349,419 acres was given 16 per cent more water. About 578,000 acres of the erstwhile PEPSU had very low water allowance and this zone was provided with 63 per cent more supplies. Another 1,051,000 acres of PEPSU area was given 20 per cent more water. The canal was to be run on the same pattern as Bhakra canals. These proposal increased the GCA to 4877,176 acres out of which CCA was 4116,966 acres. This fixed the requirement of full supply at 15,655 cusecs.

However, to keep the remodelling cost low certain steps as listed below were taken. The command areas of Kotla Branch and Choa Branch of the Sirhind canal system were transferred to Bhakra canal system. This reduced the requirement of water to authorised supply of 12625 cusecs. Some areas lying at tail end of the system were also transferred to the Sirhind Feeder so that these area could utilise Ravi-Beas water instead of Sutlej waters. Remodelling of the Rupar weir and some other works was undertaken in 1954 which is discussed next.

3.3.7. Remodelling of Rupar weir in 1954 : To suit post-Bhakra Stage, the Rupar Headworks was remodelled in 1954. The capacity of Sirhiud canal was raised to 12,625 cusecs and another canal known as the Bist Doab canal was taken off from the right bank. It was considered that due to improved approach

condition the silt trouble on the left bank canal system had improved consequently placing extra silt load on the right bank canals, so construction of a silt excluder was considered necessary.

The revised flood limit of the headworks was fixed at one lakh cusecs to the limit of flood when off-taking canals were to be closed, to prevent excessive silt entry. The limit for sluicing or flushing of sediment was fixed when the level of sediment on the pocket came within 2 feet of the level of the crest. A set of undersluices, three bays of 60 feet were provided on the right side as well and the first bay was sub-divided into three sub-bays to accommodate silt excluder, which consisted of three reinforced concrete barrels of width varying between 4.0 ft. and 5.25 ft. but of constant depth.

The shuttered weir was replaced by a proper gated barrage which provided improved degree of control over the river flows.

During the remodelling phase, part of the area of the Grey Canals Group of inundation canals was covered through a new channel, Sidhwan Branch which branched off from Manpur Head near Doraha.

The new command area of the Sirhind canal after remodelling rose to over 20480 sq. kms and covered districts of Ludhiana, Patiala, Sangrur, Bhatinda and Faridkot.

It was also considered essential to provide an all weather access across the river, instead of a ropeway, as existed before remodelling, So an A.R. Bridge was constructed at a cost of Rs. 42.93 lakhs and it provided a shortest link between the new capital of East Punjab, Chandigarh and towns in the district of Hoshiarpur, Gurdaspur, Kangra, etc.

The rest of the weir, excluding undersluices, was divided into 32 bays of 60 ft. width each and weir thickness 6.8 ft. The whole length of the barrage was divided into four portions by three groyne walls extending down stream.

The Sirhind canal, after remodelling proved to be a highly profitable venture. It irrigated an area of 26.4 lakh acres in 1960-61 and yielded a return of 26.7 per cent on the capital

(ii) There were no guide works to lead water from the choe of very wide width to superpassage—an RCC trough of smaller width. This resulted in oblique approach of the flow which resulted in stilt water pocket on one side which led to siltation.

In one case, R.D. 79699 (ft.) a syphon crossing suffered damage which was attributed to wrong design. Firstly the run-off had been under estimated, as Dicken's formula was used instead of Borton Society Formula generally in vouge and secondly masonry arch roof had been used for the syphon. The above form of roof was unable to resist uplift pressure.

During the year 1985 there was a cloud burst which caused extensive damage to Jalandhar Branch resulting in breaches at a number of points. During the year 1988, the flood water over-topped and entered the main canal and the Jalandhar Branch as the existing cross-drainage works could not take the huge run-off. This caused breaches of both banks and also deposited huge quantity of sediment in the canal system. The damage was also caused to the Rupar-Nawanshar Road. Havoc was caused by the following cross-drainage works:

Rail Magra Choe R.D. 19649—Bist Doab Canal
Tonsa choe R.D. 28139—Bist Doab canal
Bhalla choe—Purbi and Pachmi R.D. 37581 and
R.D. 38951—Bist Doab canal
Bharthala choe R.D. 45185—Bist Doab canal
Kishanpur choe R.D. 49446—Bist Doab canal
Balachour choe R.D. 79700—Bist Doab canal
Garhi choe R.D. 84000
Mahilpur choe R.D. 128500—Jalandhar Branch
Mahlawali group of choe R.D. 163600—Jalandhar Branch
Nasrala group of choe R.D. 203760—Jalandhar Branch.

3.3.10 Sidhwan Branch : This channel off-takes from R.D. 195,000 of the Sirhind canal and covered part of the area earlier irrigated by the Gray canal system-an inundation system which was supposed to cease to work after working of the Bhakra Dam due to reduced flow from Nangal. This new canal was built under the Bhakhra-Nangal Project, It linked the old inundation canals of Daulatwah, Kingwah, etc. which were fed directly from

the River Sutlej in pre-Bhakra phase. The Sidhwan branch extended perennial irrigation to vast areas of Ludhiana, Faridkot and Ferozepur districts and its CCA amounted to 424,000 acres.

3.4. Construction of Harike Barrage

The work of construction was started in the year 1948. The barrage was located on the left side of the main river stream formed after confluence of the River Beas and River Sutlej and the river was diverted through the completed structure. The estimated cost of the Barrage was Rs. 852 lakhs. It was a reinforced concrete structure, designed according to the Khosla's Theory, providing three lines of sheet-pile cut-off. The barrage has got 22 bays and undersluice pocket on the left comprising of 9 bays which was separated from the barrage bays by a divide wall. To have effective control over silt entry, a silt excluder comprising of 12 tunnels provided with downstream gated control was provided with entire width of the two-head-regulators of the off-taking canals. The pond level upstream was fixed at El-700 (ft) and the Harike Lake so created upstream of the barrage provided an initial flood absorbing capacity of 2960 million cubic feet (83.75 million m^3) which was considered necessary to avoid wastage of water down-stream of barrage and also to absorb sudden fluctuations of supplies reaching there. The barrage was fitted with vertical lift gates which could be operated either through electrical lifting gear or manually.

3.4.1. Off-taking Canal's Head Regulators : The head regulator for combined flows of the Ferozepur Feeder and Sirhind Feeder had a capacity of 11500 cusecs and that of the Rajasthan Feeder located on the left upstream of the head-regulator of the Ferozepur Feeder, had a capacity of 18,500 cusecs.

3.4.2. Commissioning of the Barrage : The work of construction of the Harike Barrage was completed in 1952 and the river was diverted through the completed structure before the flood season of that year. The work of the Head Regulator for the Rajasthan Feeder was completed along with the main work but bays were blocked with masonry and were opened in spring 1964 when Rajasthan Feeder was ready to receive the flows.

3.4.3. Operational Problems at Harike Barrage : The pond created upstream of Harike Barrage started operating in 1952

and by 1973 it was found that it had lost about 42.3 percent of its storage, the annual loss being about 3.5 per cent. The lake also got infested with water hycinth growth and it covered nearly ⅘ of the surface area of the lake of 16 sq. miles. Surface area, which led to large loss due to evapo-transpiration through weed and created operational problems.

3.4.4. Off-taking Canals of Harike Barrage : From the left bank three canals, Makhu canal, Ferozepur Feeder and Rajasthan Feeder off-take. These are discussed next.

3.4.4.1. *Makhu Canal* : The construction of Harike Barrage enabled to provide irrigation to part of the old Grey Canal areas through Makhu Canal. It had an irrigation potential of about 34,000 acres and had been fully utilized in a few years. The system involved construction of main canal and branches totalling 35 miles in length and distributary system more than 125 miles. The GCA of the Makhu Canal is 77,382 acres and CCA 20692 acres. The area irrigated in 1963-64 amounted to 16019 acres. The Grey Canal system which comprised of series of inundation canals which took off from the left bank of the River Sutlej between Phillour and Ferozepur, irrigated an area of 425000 acres. The total area of Grey canal was covered by the Sidhwan Branch and Eastern Canal in addition to the Makhu Canal.

The position of irrigation from the Makhu Canal System in 1975-76 amounted to CCA 107, 521 acres, area irrigated during Kharif was 36956 acre which constituted 34 per cent of CCA. During Rabi 1975-76 the area irrigated was 37, 087 acres.

3.4.4.2. *Ferozepur Feeder* : This channel off-takes from the left bank of Harike Barrage and it aimed to feed both Bikaner Canal and Eastern Canal from a new source, Harike Barrage instead of Husseniwala Headworks. It also carried the supplies of the Sirhind feeder for eleven miles, (to point RD 55,000) from where Sirhind Feeder took-off and the Ferozepur Feeder took a sharp turn towards right. The channel had been provided with double-tile lining and side slope of 1.25=1. The construction of the Ferozepur Feeder was completed in 1955-56 at a cost of Rs. 6.6 crores. The authorised full supply capacity at its head is 11, 192 cusecs.

3.4.4.3. *Sirhind Feeder* : Some eleven miles down from head of the Ferozepur Feeder, Sirhind Feeder off-takes. Rather the channel in the straight alignment continuing down stream is called Sirhind Feeder channel taking a turn towards right is the Ferozepur Feeder. The channel is lined with double-tile lining and channel has side slope of 1.25=1. The canal has a capacity of 4762 cusecs at head and its total length is 88 miles.

The Sirhind Feeder had been constructed to provide irrigation facilities to 1,700,000 acres of the old Sirhind canal and Bhakra Canal area, which earlier received Sutlej River waters. The Sutlej supplies were far below the requirement of the area that depended upon these supplies. To remove the shortages, the source of supply of about 1,700,000 acres was diverted to the Ravi-Beas Supplies through Harike Barrage. The saving available was utilised to improve the irrigation in the balance Sirhind canal command.

The Sirhind Feeder built at a cost of Rs. 5.9 crores was opened on July 1, 1958 for irrigation.

3.4.4.4. *Bikaner (Gang) Canal* : The Bikaner Canal was built in 1928 at a cost of Rs. 3.32 crores. Its full supply capacity at head was 2144 cusecs. It had been provided with kankar-lining. As already discussed, the canal due to design defects could not carry its authorised supply on commissioning. Slowly the lining deteriorated further. During floods of 1947, large patches got damaged. Earlier the Bikaner canal was fed from the Husseniwala Headworks but after construction of the Harike Barrage and the Ferozepur Feeder, it came to be fed from Harike Barrage. Thereafter, the reach of the canal upstream of the out fall of the Ferozepur Feeder into Bikaner canal at RD 45,000 (ft.) was abandoned.

Since the Bikaner canal was unable to carry the authorised supplies, so in Feb. 1975, its depth was increased from 9.9 feet to 11.1 feet and L-section was revised. This led to adding of brick lining resting on the top of the old lining of kankar. For the revised L-section, the coefficient of rugosity adopted was 0.018 instead of 0.013 adopted at the initial design, in 1928. Free board of 2.5 feet was provided. But at the time of remodelling most of bridges were not raised and 21 bridges out of 33

village road bridges remained to be submerged to the extent of one foot or more.

During April 1979 a closure was obtained for constructing diversion at RD 16705 (ft.) for building the Jhambwali Drain Syphon and this resulted in wide spread collapse of lining.

On July 30, 1979 a breach occurred at RD 85,000 left bank and on account of that, discharge of the canal was reduced to 1250 cusecs, which was about 50% of the full supply capacity and this resulted in drop of water level in the canal by about 4.0 feet which led to failure of lining at a number of locations.

During December 1979, seepage losses occuring from the Bikaner Canal were measured by inflow-outflow method for a length of 9.0 Kms., reach RD 95,850 ft. to RD 128,787 ft. The seepage losses per million square foot of wetted area was found to be 22.1 cusecs. The coefficient of rugosity value was found to vary between 0.0185 and 0.197 (average value of 0.019).

3.4.5. Rajasthan Feeder Channel : Signing of the Indus Water Treaty of 1960 and the Inter-State Agreement of 1955, which provided 7 MAF additional water to Rajasthan State, led to finalisation of the Rajasthan Canal Project, which provided for the construction of a 110 miles long feeder channel located in Punjab, called Rajasthan Feeder. This channel off-took from the left bank regulator of the Harike Barrage and had authorised full supply capacity of 18,500 cusecs. Its first five miles length is kept unlined as in this reach water table was high. The construction of the Feeder was taken up in 1958 and was commissioned in July 1964. The feeder has a common bank first with the Ferozepur Feeder and then with the Sirhind Feeder and its minimum width was kept as 100 feet. The Feeder has been lined, double tile lining on side and single tile lining at the bed and side slope of 1.5=1.

3.5. Husseniwala Headworks of Ferozepur on the River Sutlej and off-taking canals.

3.5.1. Historical : The lower riparian tract on both sides of the River Sutlej was being irrigated by a large number of inundation canals whose supplies were always uncertain due to

withdrawls in the upper reaches. Since 1854 different proposals had been put forward for irrigation of the area down stream of Ferozepur and these proposals eventually culminated in the great Tripple Canal Project of 1901-03 under which surplus supplies of the River Jhelum were to be used for irrigating 'Ganji Bar' areas through Lower Bari Doab Canal. So the water of the rivers Sutlej and Beas were released which could be used for extension and improvement of irrigation in the area served by the inundation canals of the River Sutlej off-taking below Ferozepur located on both right and left banks of the river.

The entire perennial supply of the River Sutlej had already been utilised in Sirhind canal and so the Beas supplies were available for utilization. Several projects were prepared between 1906 and 1908 but were abandoned due to dispute between the British Punjab and Bahawalpur State on sharing of Sutlej waters. In 1906, the Bikaner State also raised claim over the Sutlej waters to which Bahawalpur State took strong objection.

In September 1920 an accord was reached which fixed the share of the three states, the Bikaner State, the Bahawalpur State and the Punjab State (British India) for use of the Sutlej waters. The rights of the riparian states were safeguarded under clause 13 of the agreement, vide which the Bikaner State was to pay 'seigniorage' to the Punjab Government on the water supplied, at a rate not exceeding one tenth of the average water-rate on the British perennial canal system in Punjab. Thus the right of the riparian State was recognised while making available water to non-riparian state of Bikaner.

Under the powers of the 1919 Act of the Government of India which granted greater autonomy to the various provinces and the provisions of this Act ended the need for submission of irrigation project to the Secretary of State of India for approval, though the projects were still required to be referred to the Government of India and the Governor-General gave direct authorisation for each project. Under this authority the first project which received sanction was the Sutlej Valley Project and this happened on December 15, 1921.

The S. V. P. (Sutlej Valley Project) sanctioned was a gigantic one and it involved construction of four barrages at Husseniwala, Sulemanki, Islam and Panjrad.

The first work of S. V. P. to be taken up was the construction of Husseniwala Headworks (Ferozepur) and for the first time the concept of old open shutter type weir was replaced by fully gate controlled barrage. The canals off-taking from Husseniwala were to absorb part of the Grey canal inundation canal system, through the eastern canal off-taking from left bank as most of the system was in bad shape.

A special feature of the S. V. P. included the extensive use of mechanical equipment in construction. Heavy earth moving machines were deployed in addition to the use of a large number of pumps for dewatering and water supply. Use was made of concrete mixers, vibrators, pile drivers, compressors, excavators, etc. Considering the availability of cement, concrete was adopted instead of the traditional lime *surkhi* concrete, the cement factory at Attock reduced the price of cement from Rs. 60 per ton to Rs. 30 per ton for the Sutlej Valley Project. Consequently the Husseniwala Headworks came to be built as reinforced concrete structure.

The barrage site for Husseniwala chosen was located about 700 feet below the Kaiser-e-Hind railway bridge built on the river Sutlej sometime earlier. The barrage was designed to handle a maximum flood of 4-5 lakh cusecs with permissible afflux of 3 feet. It had 20 bays of 60 feet each and had provisons of undersluice pockets on both sides. On the right, the undersluice bay had five bays and on the left side four bays, the width of under sluice being 60 feet each in both pockets. The work of construction of the barrage was started on Dec. 17, 1921 and the river flows were diverted in early 1927 through completed works.

3.5.2. Off-taking Canals : The off-taking canals were required to serve a belt of 300 miles long and 100 miles wide located on both banks of the river.

Right Bank Canal System—Dipalpur Canal

The Dipalpur Canal, off-taking from the right bank of Husseniwala Headworks, was a non-perennial canal, with a

maximum capacity of 7270 cusecs and served a GCA of 1,095,000 acres out of which CCA was 981,000 acres. The Dipalpur canal replaced a series of upper Sutlej inundation canals built in 1880-90. The Dipalpur canal had total length of 1566 miles and it was commissioned on October 25, 1929.

After the end of transition period of the Indus-Water Treaty of 1960 between India and Pakistan this canal began to receive supplies through links constructed by Pakistan and its feeding from the Husseniwala Headworks ceased.

1.5.3. Left Banks Canal System of Husseniwala Headworks : From the left bank two canals took-off and these were: the Bikaner (Gang) canal and the Eastern Canal, These are discussed below :

1.5.3.1. *Bikaner (Gang) Canal* : This was designed to be perennial channel with full supply capacity of 2144 cusecs. The channel was provided with 'kankar-lime' lining to reduce seepage losses. The GCA served by the channel was fixed at 750,000 acres and CCA as 650,000 acres. Since its commissioning in October 1927, this canal had never been found to be in good health. It was found to be unable to carry its designed supplies and lining had to be raised subsequently,

This was the first channel to be built as lined channel so some mistakes happened to be made in its design as there was no previous experience available of working of lined channels carrying silt laden waters. One of the mistakes was the adoption of rugosity coefficient value to be too low. A value of N (rugosity coefficient in Kutter's formula which nearly equals to n in the Maning's formula) as 0.013. On operation it was found that the canal was unable to carry the full supply discharge. Field tests carried out in 1935 gave the prevailing value of 0.0145 against design value of 0.013. The lining got deteriorated fast and in 1939 the value further deteriorated to 0154. The total cost of construction of the canal in 1928 was Rs 332 lakhs.

In September 1947, heavy floods with peak discharge of about 9 lakhs was experienced at Husseniwala Headworks, which led to several breaches in the Bikaner Canal and lining got washed away in long patches in first 20 to 40 miles.

3.5.3.2. *The Eastern Canal* : This canal replaced greater part of grey canal inundation system and it was a non-perennial channel off-taking from the left bank of Husseniwala Headworks. It had full supply discharge of 3814 cusecs and served GCA of 514,000 acres out of which CCA amounted to 429,000 acres. Construction of the canal system was completed in 1933 at a cost of Rs 258 lakhs.

In 1947-48, the Eastern canal served a gross area of 396,055 acres and CCA 349,260 acres with flow of 2576 cusecs. As a result of efforts made in post-partition period, during the First Five Year Plan Period under 'Grow-More Food Programme', its CCA increased to 364,568 acres. More water was given through reclamation shoots to existing areas for rice cultivation. An increase in discharge of 680 cusecs was affected in different distributary system. The capacity of the main canal and branches were also correspondingly increased and their banks strengthened for running extra discharge. In all, 39 miles of new channels were added to the system at an overall cost of Rs. 30.7 lakhs.

The annual irrigation in 1963-64 rose to 296,796 acres as compared to 113,647 acres in 1947-48, an increase of nearly two fold.

Since partition, the supplies of the river Sutlej component reaching Ferozepur, over which the Sutlej valley canals had no claim, were utilised for giving increased supplies to the Eastern Canal. As a result of increased supplies particularly during sowing and maturing periods of Kharif crops and the provision of reclamation shoots and new minors, there was increase in irrigation. But with the commissioning of the Bhakra Canal System, normally the above benefit would have vanished due to reduction in the Sutlej component. But by then flows of the River Ravi started reaching Harike through M-B Link and benefits were sustained.

3.5.4. Effect of Partition on working of Husseniwala Headworks : In the case of Husseniwala Headworks, the headworks fell to the share of the East Punjab and the Dialpur canal off-taking from the right bank irrigated areas of West Punjab (Pakistan). The regulation of the headworks was with the Irrigation Department of East Punjab. About five miles above the

Ferozepur Headworks a small bridge-head of the River Sutlej lay in Lahore district of West Punjab. Pakistan could construct a new barrage there to feed its Dialpur canal and thus short-circuit Husseniwala Headworks entirely, thus placing the Bikaner (Gang) canal and the Eastern canal fed from the left bank of the Husseniwala Headworks at the mercy of upstream headworks built. This fear led India to undertake construction of Harike Barrage.

4.0 AUGMENTATION TUBEWELL SCHEMES

For augmentation of canal water supplies the Punjab State Tubewell Corporation (PSTC) and the Punjab Irrigation undertook certain tubewell schemes which are briefly discussed next.

4.1 Sirhind Canal Augmentation Scheme

The PSTC undertook sinking of 300 deep tubewells along the Sirhind canal with the objective of meeting the needs of the areas located at the tail end of the Sirhind canal in Bhatinda, Faridkot and Ferozepur districts, where ground water table was not deep and being saline was unfit for irrigation. All the tubewells were drilled by March 1978 and 260 tubewells were energised and commissioned. Originally it was proposed to install 350 deep tubewells of 2 cusecs capacity each along the Sirhind Canal, an unlined channel of 65 Kms reach from Rupar to Manpur Head. Pumped water from the augmentation scheme was projected to create a potential of about 0.747 Million hectare (1.845 Million acres). Initial estimated cost of the Project was Rs. 355 lakhs. Later on, the scheme was modified to 300 tubewells, keeping the capacity same, two cusecs each and cost rose to Rs. 420 lakhs.

Implementation of the scheme was undertaken by PSTC in 1971-72 and actually 263 tubewells were installed but 240 were made operative and 23 were listed as failure. The expenditure amounted to Rs. 356 lakhs.

The project report provided that scheme would make contribution of 275 cusecs to Sirhind canal having a capacity of 12625 cusecs. The tubewells were supposed to work for about 4000 hours in a year. But with installation of 263 tubewells, out of which 240 tubewells were operative, the expected contribution came

down to 220 cusecs. The performance of tubewells was found to be much below the projected figure of 4000 hours and in 1983-84, the tubewells worked hardly for 801 hours in a year.

4.2. Augmentation Tubewell Scheme of UBDC Tract

For augmenting canal water supply in the UBDC tract, the Punjab Irrigation took up the work of installation of 150 deep tubewells of 2 cusecs capacity in UBDC tract, along Main Branch upper of Upper Bari Doab Canal and its Kasur Branch Lower. Net discharge contribution was projected as 261 cusecs. But actually only 138 tubewells were installed by March 1978.

The UBDC had authorised full supply discharge of 7000 cusecs. Original estimate cost of the scheme was Rs. 251 lakhs.

The scheme was handed over to PSTC for operation on Sept. 4, 1978. Operative hours remained low in 1982-83, maximum of 750 hours and in 1979-80 tubewells did not work even for a single hour.

4.3. Kalanaur Augmentation Scheme

In this scheme 65 deep tubewells were installed along non-perennial Kalanaur Distributary of UBDC tract. The aim of this scheme was to convert the Kalanaur Distributary Command into perennial. These tubewells were also of 2 cusecs capacity each. By March 1978, 38 tubewells were completed and energised and then it was found that there was no demand for tubewell water on part of the Irrigation Department.

5.0 MODERNISATION OF CANAL SYSTEM OF PUNJAB

5.1. The work of modernisation of canals, through lining of distributaries and minors located in the area which was either waterlogged or was about to face this threat and where ground water quality was poor (saline water) and unfit for irrigation, was started in 1974-75. By the time this programme came under the World Bank Loan Assistance 889 IN, in the year 1979-80 about 960 Kms. length of the system had been tackled, the total length involved being 14,480 Kms. The balance work was taken up under the World Bank Aided Project.

In this Project, in addition to the work of lining of distributaries and minors, the work of lining of water courses was also taken up.

During the Phase I Project, the work covered the south-western districts of Ferozepur, Faridkot and Bhatinda and the project covered a five year time-slice of the on-going programme of modernisation of canals and water courses.

Because of the relatively high cropping intensities in the area involved which required continuous irrigation, the existing canals could not be closed for long intervals for construction of lining. Consequently a new channel, generally cup-shaped section with side slope 1:1, was built adjacent to the unlined section. Most of the new channels having discharges of less than 200 cusecs were aligned within the right of way of the existing channel. Lining consisted of ½ inch layer of 1:5 cement sand mortar laid on the trimmed and compacted sub-grade followed by a ⅜ inch layer of 1:3 cement sand mortar, which was to act as a seepage barrier and was protected by a single layer of common brick laid flat (3 inches thickness) in cement mortar. Lining was extended up for providing a free-board of 1.5 feet capped by a coping slab to prevent ingress of rain water behind the lining. Concurrent to the lining phase a number of structures, bridges, falls, etc had to be provided. Also outlets to suit revised hydraulic parameters were required to be installed.

5.2. Lining of Water Courses

About 2820 water courses were taken up for lining. From the experience gathered it was found that about 75 per cent of the length of water-course needed to be lined. The lined section of the water-course adopted was rectangular section (vertical side walls) made of brick masonry, with a layer of 1:3 plaster on the surface in contact with water. This in addition to reduction of seepage losses, reduced rugosity co-efficient to 0.015, thus giving a smaller cross-section. It was planned that the cost of lining of water courses would be recovered from the farmers but later on it was decided to waive off the recovery. The work of lining of water courses was carried out by the Punjab State Tubewell Corporation.

The area covered by the water courses lined during Phase-I Scheme covered 0.5 million hectares (1.235 million acres) and involved length of 15,200 kms. which was lined at a cost of *Rs 162.9 crores. The area covered lay mostly in the south-

western districts of Punjab where ground water was saline. Some work was done in 'Khare Majaha' area of UBDC where water of similar quality to that in south-western districts, was encountered. In the lined water courses, sheet-steel shutters were provided and permanent *nakkas* were built in masonry. Crossings were provided over the lined water courses to permit crossing of bullock carts, tractors, etc. The slope of water-courses lined was fixed at 0.2 per thousand and free board of 3 inches. The velocity attained in lined water course varied from 0.776 ft/sec to 1.371 ft/sec with 1.0 ft/sec for 2.0 cusecs water course.

6.0 BHAKRA-NANGAL PROJECT

6.1 Construction and Cost

The Bhakra-Nangal Project came to successful completion in 1964 when the Bhakra Dam was completed but the canal system was commissioned about ten years earlier in 1954. It provided irrigation to 1,460,000 hectares which lay in Punjab (550,000 ha), Haryana (680,00 ha) and Rajasthan (230,000 ha). Construction involved building of Nangal Dam, Nangal Hydel Channel alongwith two power houses (77 MV installed capacity each) at Ganguwal and Kotla, Bhakra Main Line and associated network of canal system, in addition to Bhakra Dam which provided a live storage of 6.34 MAF, the canal system comprising of 108 miles long Bhakra Main Line, branch canals of 690 miles and distributaries and minors 2100 miles long. The canal improved irrigation in old areas amounting to 1.41 million hectares and added irrigation to 2.63 million hectares. The estimated cost of the Bhakra-Nangal Project was Rs. 103.18 crores. Some areas of WYC (Sirsa Branch) were transferred to Bhakra Canal System for being irrigated through Sirsa-Munak Link built at a cost of Rs. 1.42 crores. Areas irrigated by Ghaggar Canals, Sarusti canal were also transferred and included in Bhakra Nangal Project command.

The work on the Bhakra Nangal Project is officially dated 1946 when some preliminary work on Nangal Barrage was started, but Bhakra Dam was taken up in April 1948, when work on left diversion tunnel was started.

6.2 Bhakra Dam

6.2.1. Historical : The idea of building a dam at Bhakra gorge actually dates back to 1908 but it was not until 1919 that a

project was elaborated for reservoir **EI 1500** with the construction of the Sutlej Valley Projects canals. The run off river supplies, for perennial irrigation from the two southern rivers of Punjab, the Beas and Sutlej, were completely utilised. For further expansion of perennial irrigation from the rivers, storage works were obviously necessary. So in 1927 an expert committee was appointed by the Government to advise on the suitability of building a dam near village Bhakra on the river Sutlej. Its height was restricted to 500 feet (152.4 m).

In 1944, Dr J. L. Savage, Chief Engineer to USBR (United State Bureau of Reclamation) examined the site and reported that a dam with a maximum reservoir level at EI-1600 could be built at the site, provided adequate remedial measures were taken to confine and retain major clay zones, when such strata were closely adjacent to the dam or covered by the same. Dr Savage also chalked out a detailed programme for foundation exploration, which was carried out during 1945-46. At the request of Punjab Government, the International Engineering Company of Denver (USA) prepared contract designs for the dam with maximum water surface elevation at EI 1580. The maximum elevation was limited on account of restriction imposed by the Ruler of Bilaspur State to save his palace and temples. After Independence, with the intervention of Prime Minister of India, Pandit Jawahar Lal Nehru, the Raja of Bilaspur withdrew his objection to high water in the reservoir, so the dam with maximum water level at EI 1680 was decided upon. For maximum safety, considering the type of foundation material encountered, 'Straight Gravity Concrete' section was adopted. The geology of the dam site presente a complex problem due to variation in dep and strike of the rock strata from lower to higher elevations with intervening bands of clay stone and shear zones. Another difficulty which had to be faced was the problem of finding an adequate space for all essential construction facilities, power houses, etc., within the steep and narrow gorge. Deep curtain grouting and drainage had to be provided to ensure adequate stability to the dam.

6.2.2. **Construction Phase** : As already stated the construction of the diversion tunnels started in April 1948, with left tunnel being taken up first. Both the diversion tunnels of 50 feet

diameter and each tunnel about half mile long were completed and the river diverted through them in 1954 by building two coffer dams and work of excavation in the river-bed was started thereafter. The depth of excavation involved was about 260 feet below the normal river bed. Concreting operations started in Nov. 1955 with laying of the first concrete bucket by Pandit Jawahar Lal Nehru, Prime Minister of India with the usual fan-fare and concreting to full height was attained in late 1961. The dam was officially dedicated to nation by Pandit Jawahar Lal Nehru on Oct 22, 1963, though all the civil engineering works were completed in mid 1962.

To effect temperature, which is an important and necessary operation in placing of mass concrete in gravity dam, was effected by pre-cooling aggregate to 43°F, using chilled water during mixing and also circulating cool river water through a net-work of pipes embedded at various lift levels. Also puzzolana was used (20 parts puzzolana 80 parts cement) to reduce heat of hydration.

6.2.3. **Early Irrigation** - Before the dam reached full height storage was effected in the dam by partial regulation of flows through right diversion tunnel, right from Kharif of 1958 when the left diversion tunnel was blocked. The irrigation effected through this effort is shown in Table below :

Table : Sowing early irrigation affected through regulation of flows of right diversion tunnel of Bhakra Dam.

Year	*Storage utilised (M.A.F.)*	*Area Irrigated (Million acres)*
1958	0.72	—
1959	1.75	1.712
1960	2.10	1.818
1961	3.70	1.670
1962	4.80	1.858
1963	6.05	1.915
Total	19.12 M.A.F.	8.973 Million Acres

6.2.4 Mishap in the Hoist Chamber : Regulation of supplies connected with 'early irrigation' was effected through operation of two hydraulically operated high-head slide gates each weighing 74 tons which were provided with two emergency gates. The operations hoists were located in the hoist chamber constructed above the right diversion tunnel which was approachable through visitor's gallery. The right tunnel was eventually plugged with concrete, but before that stage was reached, a mishap occured on August 21, 1959, one month before the closure date, which resulted in failure of the hoist chamber floor. Thirteen lives were lost and also flooding of the left power house occurred through connecting gallery system. At the time of accident there was 280 feet depth of water in the reservoir against partially completed dam and it was 215.5 feet above the floor of the hoist chamber when the floor gave way and water rushed from the chamber to the adit tunnel and through visitors' gallery into the left power house at the other end of the dam, where it submerged generators under erection.

The right diversion tunnel had to be plugged under nearly 164 feet head of the fast flowing water. Successful closure of tunnel was effected by Feb. 1960 which was a unique engineering feat. Help of navy divers was taken. The eventual solution to this catastrophe was to drop over 0.5 million tons of clay, rock and sand in layers and of concrete and puzzolana in crates from barages on to the tunnel mouth untill it was sufficiently sealed for a new adit to be driver to the gate and hoist chamber which was finally sealed with concrete by March 1960. Meanwhile the reservoir had come down by about 100 feet and pressure in tunnels reduced. This delayed the completion of the dam and it took about 14 years.

6.2.5. Cement for use at Bhakra was obtained in bulk in special hopper-bottom wagons from Surajpur Factory of A.C.C. Ltd. near Kalka. The wagons were emptied into track hoppers feeding directly through cement pumps, to six storage silos of 1000 tons capacity each. The peak demand of cement was rated at 900 tons per day (45 wagons) and the storage silos could provide about one week's supply.

The mix evolved was 2.75 bags mix (2.75 bags of cement per cubic yard of concrete) which contained puzzolana admixture. The resulting mix was found to give concrete which was 38 per cent more impervious than usual non-puzzolana concrete of same strength.

6.2.6. For placing concrete steel trestles with travelling double cantilever and revolving cranes, were used. Concrete from the batching and mixing plant was transported in 4½ cu yds buckets loaded, five at a time, on a flat car which travelled on track laid on top of trestles. The cranes picked up concrete buckets and deposited in place, where concrete was compacted by means of high frequency electric vibrators. Height of concrete placed in one lift was kept as 6 feet and cantilever type shuttering was used. 'Clean up' operations, on top of each lift was done through 'Sand-blasting' and air-water jets. Necessary provision for sizing, drying and storing the required sand was made.

At the peak activity the scenario at Bhakra gorge presented a unique combination of 'men' and 'machines' amidst roaring trucks, whirling cranes, chattering pneumatic tools, 13,000 workers, 300 engineers and 30 American Experts grappling with the forces of nature to built mighty Bhakhra Dam, which was rightly called as 'Modern Temple' by Pandit Jawaharlal Nehru. The left power house started generating electricity two years before completion of the dam.

6.2.7. Salient Features of Bhakra Dam : Salient features of the Bhakra Dam are given below :

Length of the dam at top — 1700 feet and 30 feet wide roadway.
Maximum height — 740 feet above deepest point excavated.
Gross Storage at El 1685 — 7.8 M.A.F.
Live storage at El 1685 — 5.83 M.A.F.
Dead storage with El 1462 — 1.90
Catchment — 22,000 square miles
Spread of reservoir — 65 square miles, length 60 miles
Mean annual run-off — 13.6 M.A.F.
Maximum observed flood (in 1971) — 6.08 lakh cusecs
Spillway over-flow type, total width 260 feet and effective width 200 feet, provided with two tires of river out lets at El 1420 and El 1320. The flood passing capacity with reservoir

level El-1685. Spillway—197,300 cusecs and sixteen 8.67 feet horse-shoe river outlets—98,352 cusecs, total 295,652 (At El 1420—56.56 cusecs each for eight outlets).

Maximum reservoir level permissible during flood routing—El 1685.

Reservoir to be filled El 1680 and above that flood storage capacity.

Gates and Gearing—Four radial gates of 50 feet×47.5 feet high provided. Energy dissipation — normal horizontal stilling basin with divide wall for enabling repair of each compartment.

Power Houses

Left bank — 5 units of 90 MW=450 MW
(recently up-rate to 100 MW each)
Right bank — 5 units of 120 MW=600 MW
Total cost of Power Houses — Rs. 91.52 crores
Galleries — Total length 3 miles.

Diversion tunnels — Two tunnels fifty feet diameter each and half mile long each tunnel, total cost Rs. 3.6 crores. Thickness of reinforced concrete lining varied from 3 feet to 6 feet. This was in addition to tunnel ribs provided to take load.

Number of towns and villages submerged : 371 having population of 3600.

Total cost Rs. 52.53 crores.

Summing up the words of Pandit Jawahar Lal Nehru are cited, "Bhakra Nangal Project is something tremendous, something stupendous, something which shakes you up when you see it. Bhakra is the new TEMPLE OF RESURGENT INDIA and is the symbol of India's progress."

6.3. **Nangal Dam** : Nangal Dam is situated on the River Sutlej 8 miles down stream of the Bhakra Dam. It has got 26 bays of 30 feet length each. It is founded on congloemerate (cemented gravels) and is 95 feet high above the deepest foundation level to the top of breast wall. It has been designed to pass a flood of 3.5 lakh cusecs. The dam diverts the water of the river Sutlej into the Nangal Hydel Channel for irrigation and power generation purposes. The Nangal Pond acts as a balancing reservoir 240,000 acre foot to smoothen out the diurnal variations

in releases from the Bhakra Power Plants. It costed Rs. 10.13 crores.

Nangal Dam consists of 955 feet long concrete dam which carries a barrage, rail-cum-road bridge across the river Sutlej The historical background of the project is that during the period of the world war II, Punjab (pre-partition state) suffered from an acute power famine and a stage was reached when bare requirements of even public hospitals and schools could be met with some difficulty, not to speak of power being made available to private sector. So Nangal Project was conceived to be an answer for the problem. In the beginning, there was some discussions regarding the advisability of gains ahead with the construction of the project, in view of the large quantity of power that would become available on completion of the Bhakra Dam. But the power-famine became so acute that it was not considered desirable to wait any longer and construction of Nangal Dam was taken up in 1946.

The site for the Nangal dam selected was highly suitable because the approach channel was straight and narrow and also the banks were fairly high and from which obviated the necessity of expensive river training works. The dam 955 feet long provided an effective waterway of 780 feet which was covered through 26 bays of 30 feet width each separated by 7 feet wide piers.

Explorations of foundations was carried out which revealed presence of 'massive conglomerate' (cemented gravels) with interlocked laminations or pockets of sand at different depths. These laminations of sand affected water tightness or impermeability of the foundation strata seriously. The design of the dam was worked from Khosla's theory applicable to design of structures on pervious sub-soils. Section of dam adopted was solid gravity with upstream and downstream floors, curtain walls all built in plain cement concrete. Its piers were designed for maximum pressure, likely to be transmitted by gates and the breastwall (a measure to reduce the height of the gate required to be provided) and the full load on the road and railway bridge. They were also required to be safe to withstand a transverse water head of 10 feet. Its abutments have been built in plain concrete and were designed as retaining walls to withstand the maximum earth and hydrostatic pressure. All piers were taken down

to be founded on conglomerate and the rest of the structure downstream of the deep curtain wall under the gate line, was built on gravel or conglomerate depending on the type of material met with at the design level. Locations where conglomerate was met at level higher than design level advantage was taken to reduce the thickness of the concrete floor. A minimum thickness of 4 feet was prescribed and maintained. The down stream floor was provided with a net-work of sub-surface drains which were intended to reduce uplift pressure acting on the floor and these drains ended in a trench filled with gravel and sand, surrounding the down stream curtain-wall. Further relief in uplift pressure was provided by means of a row of drainage holes provided immediately down stream of the axis of the dam and two sets of pipes opening on the sides of the main piers, former opened out in the foundation gallery and the latter two feet above the minimum tail water level. Piers were extended downstream, so as to act as inverted support for cistern floor and dummy piers were also provided midst way of each bay which also served the same purpose. Expansion joints have been provided all around the main body of the concrete dam, to take care of differential settlement of foundations or that due to variation in temperature.

6.3.1. **Silt Excluders** : To exclude the entry of rolling boulders and shingle into the canals, a double-decked shingle excluder had been provided in the first two bays of the barrage, adjacent to the canal head regulator. The structure consisted of twelve tunnels flow through which was regulated by means of special gates located at the downstream end. Damage to the excluder occurred in 1960 when its slab got uplifted while gates were being operated. This resulted in leakage from the reservoir to downstream and to control that shingle excluder had to be plugged in a very nearby the same manner done in the case of the right diversion tunnel of Bhakra Dam while closing leakage from hoist chamber.

6.3.2. **Gates and Gearings** : The gates for the barrage provided were of 'Stoney Type' two tiered counter balanced gates with which it was possible to head up water upto El 1154 through 42 feet above the crest of the dam. These gates worked in the same groove on the either side. At the top edge of the gate rubber seals were provided which bolted against the breast wall edge.

These gates are operated from an over-head steel structure built on top of piers. For repairs and inspection of the main gates provision had been made of bulk-head gates operated by means of cranes running on the bulk-head gate bridge.

6.3.3 Head-Regulator : Head regulator of the hydel channel has been designed to pass a maximum discharge of 14500 cusecs (which includes 2000 cusecs for the silt ejector) with a minimum loss of head (a head-less structure). The water way provided at the head-regulator is by eight bays of 24 feet clear span separated by 6 feet thick piers. The axis of the regulator is inclined at 102.5° with respect of the axis of the dam i.e. 12.5° off normal. The crest of the regulator was fixed at 1125 feet i.e. 13 feet higher than the barrage crest. The regulator has two sets of gates, the lower gate 4 feet high functioned as raised cill behind the crest and the upper gate bulted against the downstream face of the breast wall which was 22.4 feet high with its bottom edge E.I. at 1137.6 feet. Provision had been made for lowering bulk-head gates upstream and downstream of the main gates to enable inspection and repairs of the main gates and the concrete structure without having to close down the canal.

6.3.4. Construction Phase : High strength concrete and stone facing had been used at points subjected to abrasive action of rolling shingle and boulders. But points of most severe attack were armoured with steel plate liner such as pier noses and the upstream lip of the shingle excluder. In order to save from work the piers had been faced with precast concrete blocks and these were constructed successively to 2 feet to be filled with mass concrete.

Construction work was started in December 1946, but there was a brief interruption due to partition of the country in August 1947. The left half of the structure was taken up first and was completed by March 1949. After that right half was taken up and the whole work was completed in 1952. The whole construction operation was well-planned and rapidly executed without abnormal difficulty. A record flood of 3.10 lakh cusecs was successfully passed by the new structure partially completed, on August 22, 1951 and no serious damage was reported.

6.3.5. Foundation Gallery : In order to have an excess to the foundation, an inspection gallery of 5 feet x7 feet have been

provided in the body of the dam at El 1067. Through this gallery grouting of foundation was carried out but the main purpose was to provide an outlet for seepage or to act as drainage galleries to keep a check on the uplift pressure on foundations.

6.4. Nangal Hydel Channel : This off-takes from the left bank of the River Sutlej, first above Nangal Dam and is 40 miles long. The natural fall along the channel is utilised at Ganguwal and Kotla to develop power. The channel passes through an extremely difficult sub-mountaneous region, especially in its head reaches. It involves both heavy cutting and high filling reaches. Fifty eight torrents having total run-off of more than 3 lakh cusecs cross the channel through syphons, adueducts, super passages. The canal has an authorised supply at 12500 cusecs. For pre-Bhakra stage to prevent silt entry, a silt ejector had been provided at RD 10,000 feet which utilised discharge of 2000 cusecs.

6.4.1. The work on the Nangal Hydel Channel was started after independence, August 15, 1947. The width of the channel has been kept as 58 feet, depth 23 feet, side slopes 1.25:1. The canal has been lined with concrete lining of 1:3:6 nominal mix five inches thick in the bed and 6 inches thick on the sides. Pressure release arrangement of suitably packed graded-filter had been provided in the reaches where soil was semi-pervious, because it was considered that in case of pervious well draining sub-strata and also the impervious reaches there would not be any problem of differential hydro-static pressure.

In the high filling reaches the banks of the channel were designed as low earth dams meeting all the requirements of stability in steady state and also for sudden draw-down condition. The material placed in banks was suitably zoned.

6.4.2. O & M Experience : The Nangal Hydel Channel was commissioned in July 1954. Its lining proved to be relatively more stable in the filling reaches compared to that in curring reaches. Ever since it was commissioned it has not been possible to obtain a closure to inspect and repair it. Failure of lining slabs occurred at some locations, due to unequal settlement of the back fill or subgrade on saturation which resulted in

formation of cavities underneath the slab, which were attributed to re-arrangement of soil particles due to movement with seepage water. Also there was loss of soil through joints provided in the slabs. Bulging of slabs were noticed at locations in cutting reaches due to excessive hydrostatic pressure as a result of inadequate drainage or malfunctioning of pressure release valves. Joints of the panels of lining lost sealing compound due to running water action or compound becoming brittle due to weathering action. Leakage was also noticed at some of the cross-drainage works after a few years working and the sources of leakage could not be located but it was attributed to the gradual saturation of the banks and sub-soil due to continuous seepage. On the whole performance of concrete lining was found to be better than that of the tile lining. Concrete lining had been used in 31.25 miles of the total length of 40 miles and double tile lining in the balance length. The reason for adopting concrete lining on a large scale was on account of easy availability of the aggregates and non-availability of suitable clay soil for burning of bricks.

The Nangal Hydel Channel functions as a feeder channel delivering supplies to the Bhakra Main Line near Rupar. The general water surface slope has been kept as 1/10,000 but in cutting reaches steeper slope of 1/6666 has been used so as to reduce cost. The quantity of earthwork involved in excavation amounted to 680 million cft.

6.4.3. Nangal Project Power Houses : Two power houses, at Ganguwal and Kotla are located at 12 miles and 18 miles downstream from head (Nangal) respectively. At each power house, a head of 93 feet is tapped to give the total power of 154 MW. Total cost of the two power houses being Rs. 13.7 crores. At each power house three sets are installed, two of 24 MW and the third of 29 MW, making the total of 77 MW at each Power House.

These power houses presented the most difficult foundation problems on account of high sub-soil water level involving heavy dewatering measures. At Ganguwal foundation had to be taken by about 68 feet below water table and for that well-point system was used for lowering the water table in the pit area. At Kotla some clay layers were met at foundation level which

had to be removed under difficult conditions to ensure safety of the structure. The Ganguwal Power House was commissioned in Sept. 1956 but the other took more time.

6.5. Bhakra Canal System

The Bhakra Main Line begins at the tail end of the Nangal Hydel Channel near Ropar and has a capacity of 12455 cusecs at its head. It traverses 108 miles towards south-west through Patiala and Hissar districts towards Rajasthan border. Its branches which totalled 545 miles include Narwana Branch which intercepted old Sirsa Branch of western Yamuna Canal (WYC) and the Barnala Branch which took over some command from the old Hansi Branch of WYC.

6.5.1. As the supply to Bhakra Canal System was to be through Nangal Hydel channel which received stored supply so relatively silt free water was to flow through the system. Hence during design of the channel and the connected system value of silt factor of f=0.8 was provided for silt size of 0.01 inch. But to cover the pre-Bhakra stage the system was checked for f=0.90 in the head reaches, 0.8 in the middle reaches and 0.75 for the tail reaches.

Mostly double-tile lining with a sand wicked layer of plaster had been provided in the main canal and branches. Value of rugosity coefficient adopted was 0.018 and side slope of 1.25:1 has been adopted.

The Bhakra Canal system had been planned to serve arid tracts of East Punjab and Rajasthan State. Additional demand on the Sutlej waters amounted to about 18,000 cusecs, which comprised of 12,500 cusecs for the Bhakra Canal System, 3500 cusecs additional for the remodelled Sirhind canal system and 1401 cusecs for the Bist Doab. The total area which was to benefit from the above was over 10 lakh acres out of which 6 lakh acres was new area.

Construction work was completed in 1954 but the system started taking restricted supplies from Kharif 1952 onwards.

The Bhakra Main Line branches off into Narwana Branch, Ghaggar Branch, Bhakra Main Branch and Rattia Branch. The Narwana Branch off-takes from BML at R.D. 158,000 (ft) near Sond Head.

Barring a few small distributaries taking off from Narwana Branch in the Punjab territory, most of the supplies carried by Narwana Branch irrigate areas in the Haryana State. The Ghaggar Link off-takes from R.D. 204,000 of B.M.L. and feeds mostly the old areas of Erstwhile PEPSU, canals of Ghaggar Branch, Kotla Branch and Choa Branch. The Bhakra Main Branch and Rattia Branch take off at the tail of the Bhakra Main Line near Tohana and serve mostly Haryana areas.

6.5.2. Performance of the Bhakra Canal System : Apart from the improvement effected on the Western Yumuna Canal (WYC) command and the Sirhind canal system, the development of irrigation on the Bhakra Canal System has been as follows :

The command area of the Bhakra Canal System comprised of three categories;

(i) perennial system with intensity of 62%

(ii) non-perennial system with intensity of 35% and

(iii) restricted perennial with intensity of 45%.

The total area served was as follows :

S. No.	Category	G.C.A. (acres)	CCA (acres)	Intensity
1.	Perennial	3,174,980	2,825,461	62%
2.	Non-perennial	666,870	564,397	35%
3.	Restricted perennial	1,833,230	1,556,901	45%
	Total	5,675,080 acres	4,946,759 acres	

Combined with the improvement on the Sirhind canal project, the B-N Project aimed at irrigating 3,52,000 acres per year. The area actually irrigated is shown in the following table.

Table showing performanee of the Bhakra Canal System

Year		Area Irrigated (acres)
1951-52	..	16,170
1952-53	..	46,320
1953-54	...	46,320
1954-55	..	868,890
1955-56	..	1,033,411
1956-57	..	1,213,638
1957-58	..	1,303,000
1958-59	..	1,712,020
1959-60	..	1,818,000
1960-61	..	1,700,000
1961-62	..	1,905,000
1962-63	..	2,321,000
1963-64	..	2,480,000

6.53. O & M Experience : Excessive damage has been reported to be occurring in reaches below most of the falls which was attributed to excessive fluming on the canal at the site, resulting in incomplete energy dissipation.

Due to clear water flowing during most of the time there was excessive growth of weeds in the canal system which created maintenance problems.

7.0 Beas-Sutlej Link Project Stage I & Stage II : In order to utilise water resources which became available after transition period of the Indus Water Treaty of 1960 was over, it was considered that about 3.823 MAF of Beas water would need to be transferred to the river Sutlej, to be available at Nangal rather than at Harike. For this the problem was referred to Dr A. N. Khosla, who after detailed deliberation put forward an idea of Beas-Sutlej Link Project which comprised of two units. Under Unit No. I Pong Dam near Talwara and under Unit No. II Beas-Sutlej Link through which about 7500 cusecs flow of the river Beas was to be diverted to Sutlej through a series of tunnels and open channels. The total cost of the scheme was about Rs 915 crores. The project formed a major part of the overall plan for optimum utilisation of waters of the three

eastern rivers, Sutlej, Beas and Ravi, which came to the exclusi share of India, as per Indus-water Treaty of 1960.

7.1 Beas Dam at Talwara--Unit II of B.S.L. Project

The Beas Dam at Pong (Talwara) with transfer of about 3.823 MAF of Beas water into Sutlej, the annual flow of 9.185 MAF of the River Beas (in an average year) left to be stored in the Beas Dam having storage of 5.5 MAF, the stored supplies were to be released to meet irrigation requirement of canals off-taking from Harike.

Investigation connected with the Beas Dam started in 1955 and by 1958 project designs were available. A new township at Talwara with housing facilities, workshop, stores, warehouses, was ready by 1961. By 1962 actual excavation of the diversion tunnel had started at Pong which was scheduled to be completed by 1971 but was actually completed in 1974.

A rolled earth-fill dam, 330 feet high above river bed and 380 feet above foundations. length 570 feet. Volume of earth placed was 35 million cubic yards. Its hydro potential was projected at 0.36 million KW with 6 units of 60 MW each installed in the Pong Power House at estimated cost of Rs. 110.8 crores. The preliminary estimated rate of silting fixed at 120 years after its storage would reduce to 1.0 MAF.

7.1.2. Construction Phase : At Pong, there were two critical periods, the first in winter of 1966-67, the Beas water was diverted into the diversion tunnels, five tunnels of 30 feet finished diameter, by construction of coffer dams, so as to permit excavation of foundation and its treatment. At this dam, positive cut-off through grout curtain, followed by drainage holes was established.. The second critical period during construction was during the summer of 1968 when the diversion tunnels were to be plugged and converted into irrigation outlets or pen stocks for power houses and the river rediverted. The dam was to be raised to that height to be adequate to absorb the monsoon run-off.

7.1.3. Spillway provided at Pong had been designed to pass a flood of 4.37 lakh cusecs with outflow of 3.85 lakh cusecs and was located in the left abutment and had one single stilling basin. Spillway was fitted with radial gates.

7.2.0. **Beas-Sutlej Link Unit I :** Out of the total run-off of 13.6 MAF of the River Beas, before construction of Unit I and Unit II of the Beas Sutlej Link Project, utilisation were 2.2 MAF and 11.4 MAF used to go waste. Through diversion to Sutlej and storage at Pong this potential was to be made use of. The link was envisaged to transfer annually about 3.823 MAF of the Beas water to the Sutlej, this increased the regulated flow at Bhakra from 6.3 MAF to 8.3 MAF.

7.2.1. The Beas-Sutlej link had two direct roles to play, one to transfer water into Bhakra reservoir to the tune of 7500 cusecs and the other to generate power at Dehar, followed by additional generation at Bhakra Dam Power Houses. Estimated cost of unit II was Rs. 97.0 crores. It involved construction of a 250 feet high, 1348 feet long rock-fill dam, a diversion structure at Pandoh on the river Beas. The water diverted is led through 7.2 miles long, 25 feet diameter pressure flow tunnel called Pandoh-Baggi Tunnel. At its outlet end, Pandoh Baggi control works are located which pass water through a stilling basin where remant energy is dissipated.

From stilling basin water passed down into 7.2 miles long hydel channel, a concrete lined channel, called Sunder Nagar Hydel Channel, which has its outfall into a balancing reservoir, called Sunder Nagar Balancing Reservoir. A silt ejector has been built in the Sunder Nagar Hydel Channel. At the outfall end of the hydel channel arrangement had been made to keep water level variation in the hydel channel to the minimum by maintaining a constant water level by adjusting the gate opening corresponding to discharge. Here in addition to automatic float operated gates control, over-riding manual control was provided.

From the Sunder Nagar Balancing Reservoir water is led through another 8.5 miles long tunnel of 28 feet diameter, known as Sunder Nagar-Dehar tunnel in which free surface flow occurs. At the outlet end of the tunnel provisions exist for by-passing upto 7500 cusecs into the Sutlej River. Through a shoot-spillway, which comes into play when power house at Dehar is not operating or operating at lower capacity. The Dehar Power House with six units has installed capacity of

690 MW. The additional generating of power of 148 MW at 100 percent load factor is created at Bhakra Power Houses.

7.2.2. To facilitate the construction of such long tunnels as involved in this project, two adits were provided in case of Pandoh-Baggi Tunnel and three in case of the Sunder Nagar-Dehar Tunnel. There were difficult reaches involved in the case of latter tunnel where 'squeezing-rock' or instable reaches' were involved, which delayed completion of the project to some extent. A valve chamber has been excavated as an underground structure above Dehar Plant. Three penstocks dividing into six have been provided which tap, a head of about 1000 feet through 'Francis' Turbines supplied by Bharat Heavy Electricals Ltd. From the valve house or surge shaft, a 1700 foot long tunnel took water upto 7500 cusecs to flip bucket-shoot which dissipated energy in the water and threw it in mid stream.

7.2.3. Construction of Pandoh Dam was started in October 1976 and completed in May 1977. It involved provision of gross storage of 33240 acre foot, out of which live storage was hardly 15,046 acre foot. The maximum flow of the river Beas that could be diverted was 9000 cusecs. The estimated useful life of the Pandoh Dam, which corresponded to filling up of the entire dead storage by silt, was assessed as 27 years.

Construction of the Sunder Nagar Hydel Channel was taken up in Oct. 1967 and completed in June 1977. The channel had full supply discharge at head of 8500 cusecs, surface width of 92.6 feet, depth 20 feet, water surface slope of 1 in 6666, side slope 1.5=1, free board of 4 feet and length 7.5 miles.

7.2.4. Sundernagar Balancing Reservoir of 13000 acre foot capacity was created in Sukety Valley, by building a 3000 feet long earth-fill dam. The objective of the storage was to cater for peak loads as the Sundernagar - Dehar Tunnel had a capacity of 14,250 cusecs—the maximum demand of six units of Dehar Power House at the time of peak demand where as the supply by the Sundernagar Hydel channel was of 8250 cusecs maximum below the silt ejector. So the balancing reservoir

was needed. The balancing reservoir by providing an infinite detention time and extremely low travel velocity, acted as a very efficient silt trap which was boon for the Dehar units but created O and M problems due to fast silting.

7.2.5. **O & M Experience** : The B-S-L. Project unit II was completed on July 7, 1977. Some storage had been provided at Pandoh Dam though it was basically a 'diversion structure', to cater for peak water demand to some extent and also to arrest coarse silt. Though the projected life of the dead storage to get filled with silt was fixed as 27 years, but on operation of the project it was found to get silted at much faster rate and the whole of the dead storage was lost in less than nine years. This accelerated silting rate was attributed to operation of 'Slate quarries' upstream and deforestation of the catchment, factors never considered by the planners. Another factor which increased the trap efficiency of Pandoh Dam was that in order to avoid formation of vortex in front of tunnel mouth, the reservoir level was kept at maximum level El 2915 ft. even though requirements of diversion could have been met with lower reservoir level. This resulted in greater silting. It was observed that while pit at Pandoh. which was about 50 feet deep below the intake crest, was getting silted particulary in the area away from the tunnel mouth. The silt deposited was required to be cleared through dredging.

7.2.5.1 *Sunder Nagar Hydel Channel* : During first year of its operation when it carried the maximum discharge of 7500 cusecs it was observed that seepage flow was found to oozing out at locations where filling reaches and cutting reaches joined. To locate the source of seepage radio-active tracer technique was tried with the help of Bhabha Atomic Energy Research Centre (BARC) but it was not possible to locate the source. But due to grouting measures the seepage was found to decrease gradually and also as seeping water was 'clear-free of silt, so it was not considered to pose any danger to stability of the channel.

7.2.5.2. *Sedimentation of Pong Reservoir* : The Pong reservoir was commissioned in 1974 and thereafter at regular interval observations by inflow-outflow method and also with the use of eco-sounder, were carried out to determine the rate of silting occuring. In the design stage the annual silt load was assumed

to be 49 million tons, out of which 6 million tons was considered to be bed load and rest 43 million tons as wash/suspended load. The composition of the suspended load was fixed as 42 percent fine silt, 39 percent medium silt and 19 percent as coarse silt and it was assumed that the entire fine silt plus 5 percent of the rest would pass down stream. The entire dead storage was considered to be lost due to silting in 127 to 176 years and the 100 percent loss of the live storage in 390 to 540 years. But the observed data indicated that instead of the whole fine silt sediment passing down hardly one third was passing down and the rest was getting deposited in the reservoir. Of the total load instead of 55 percent getting deposited as projected, deposition was 96.9 percent, so the projected useful life would be much smaller than that considered.

7.3. **Salient Features of Beas Sutlej Link Project Unit No. I and Unit No. II**

Unit I B-S Link : Pandoh Dam—Diversion structure—rockfill dam 244 ft high, volume of material placed 2 million cu yds. During construction river was diverted through a 30 feet diameter tunnel 2179 feet long, which could pass 19,900 cusecs flow with maximum velocity of flow 32 feet/sec.

Max. reservoir level	—	El 2941 ft.
Normal reservoir level	—	El 2900 ft.
Gross storage	—	33240 acres foot
Live storage	—	29296 acre foot
Spillway capacity	—	3.51 lakhs
Gates & Gearing	—	5 radial gates with high pressure top seal - size 39.4 ft x 42.7 ft high each. Each gate hoisted by 200 tons hoist independently.

Pandoh-Baggi Tunnel :—Cost Rs 55.71 crores. Full supply discharge 9000 cusecs — pressure flow tunnel — 25 feet diameter 8.1 miles long. Excavation involved 1.35 million cu yds rock and placement of 0.55 million cu yds of concrete.

Baggi Control Works :—Circular tunnel transitioned into four rectangular conduits — each provided with gates — down stream gate slide type and served as regulating gate while

upstream gate a fixed wheel type to work as emergency gate. Each gate operated by independent hoist.

Sundernagar Hydel Channel : 7.3 miles long having fully supply capacity of 8500 cusecs at head including 1000 cusecs for silt ejector. Lining concrete 4 inches thick in bed and 5 inches thick on sides. Bed width—31 feet, Maximum depth—20.5 ft, Side slope 1.5=1, Bed slope 1/666. Cost Rs. 27.92 crores. Excavation of 8.24 million cu yds and placement of compacted fill of 5.74 milion cu yds.

Sundernagar Balancing Reservoir : Cost Rs. 22.20 crores. Live storage of 3000 acre foot. Reservoir lengh 7000 ft. and maximum width 1500 feet. Embankment earth-fill cum rock fill length 700 ft 70 feet high. Excavation 4.75 million cu yds and placement of 2.64 million cu yds of compacted fill. Spillway—glory hole type spillway of 11600 cusecs capacity. Maximum reservoir El 2764 ft. Top of the embankment El 2777 ft.

Sundarnagar-Dehar Tunnel : Cost Rs 52.38 crores. Tunnel diameter 28 feet and 7.7 miles long terminating into surge shaft. Discarage capacity 14,250 cusecs. Total quantity of concrete placed 0.7 million cu yds and excavation involved 1.58 million cu yds of rock.

Surge Shaft—Bypass Tunnel—Bypass chute. Differential type R.C.C. surge shaft of 75 feet diameter and 411 feet height, having a riser of 25 feet finished diameter. Bypass 22 feet diameter and 974 feet long tunnel taking off from surge shaft riser. Air vent shaft of 9 feet diameter down stream of inlet to avoid air being entrapped during upsurge. At exit end tunnel trifurcated into 8 foot diameter steel outlet pipes-each transformed further into rectengular conduit to accommodate slied gate.

Dehar Penstocks : Sundernagar—Sutlej tunnel tails into a fan-shaped chamber of the surge shaft from where three penstock header tunnels take-off. Immediate downstream of header tunnel portal valve chamber constructed to house butter fly valves for each penstock header. Downstream of valve chamber penstock laid in open along sloping surface. 16 feet diameter header

bifurcates into 11 feet diameter penstocks branches at a point where design head is about 571 feet.

Dehar Power Plant : Cost Rs 45.52 crores. Building R.C.C. multistorey structure housing six units of 165 MW each—Francis turbines (BHEL) involved excavation of 0.8 million cu yds of rock and placement of 79000 cu yds of concrete. Drop utilised 1050 feet.

Unit I—*Labour force employed at peak*

Skilled and unskilled labour	36,000 men
Regular staff	2790
Engineers	540
Flow diverted	3.82 MAF

Additional power at Bhakra Power House 148 MW.

Unit II-Beas Dam at Pong :

Dam height 435 feet, reservoir impounds 6.95 MAF with live storage of 5.91 MAF. Excavation involved 39 million cu yds and placement of 46 million cu yds of fill material and 1.47 cu yds of reinforced cement concrete. Cost Rs 38.31 crores. Length of the dam at top 6155 feet.

Diversion tunnels : Cost Rs. 24.86 crores. Five tunnels of 30 feet diameter of aggregate length of 16,459 ft. Two tunnels converted into penstock tunnels and two irrigation outlets. Intakes provided with suitable trash rocks located on excavated bench of El 1230 ft. Penstock tunnels provided with emergency gates size 10 ft. × 21 feet operated from hoist structure located at top of the dam or through control chamber floor at El.1127.5 ft.

Spill way : Chute type—Designed to pass a flood of 11.85 lakh cusecs with maximum discharge of 4.37 lakh cusecs. Crest level—El 1365 ft., six number radial gates of 47.5×40 ft. driven by electrical mechanical hoists. Involved excavation of 8 million cu yds of over burden and placement of 0.55 million cu yds of reinforced concrete, involved drilling, grouting and placement of 0.65 million feet of steel anchors.

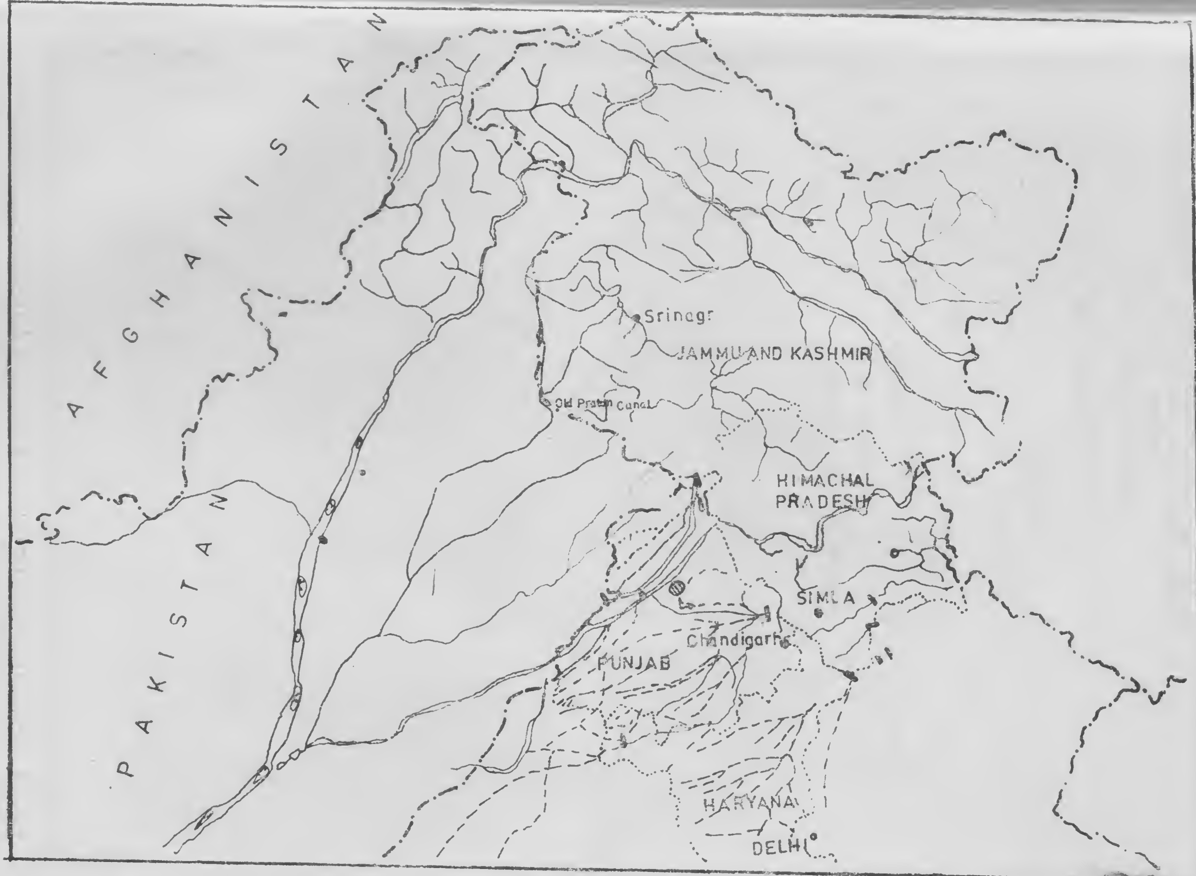


Fig. 1 Irrigation Map of the Punjab Region (Based on the Irrigation Map of India 1978 Published by C.B.I. & P New Delhi)

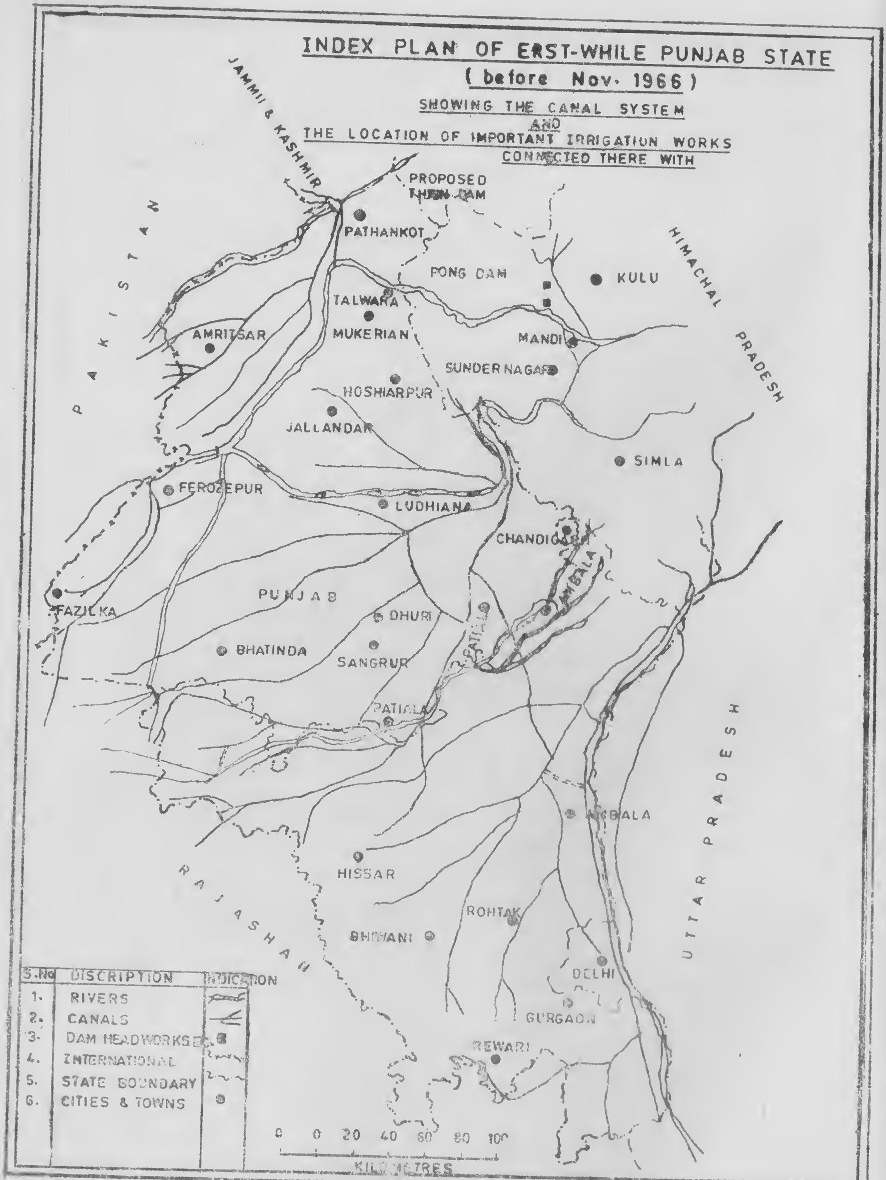


Fig. 2 Showing Canal System of the Erst-While Punjab State
(before Nov. 1, 1966 i.e. = organus)

SHOWING CANAL SYSTEM OF THE PRESENT DAY IN PUNJAB

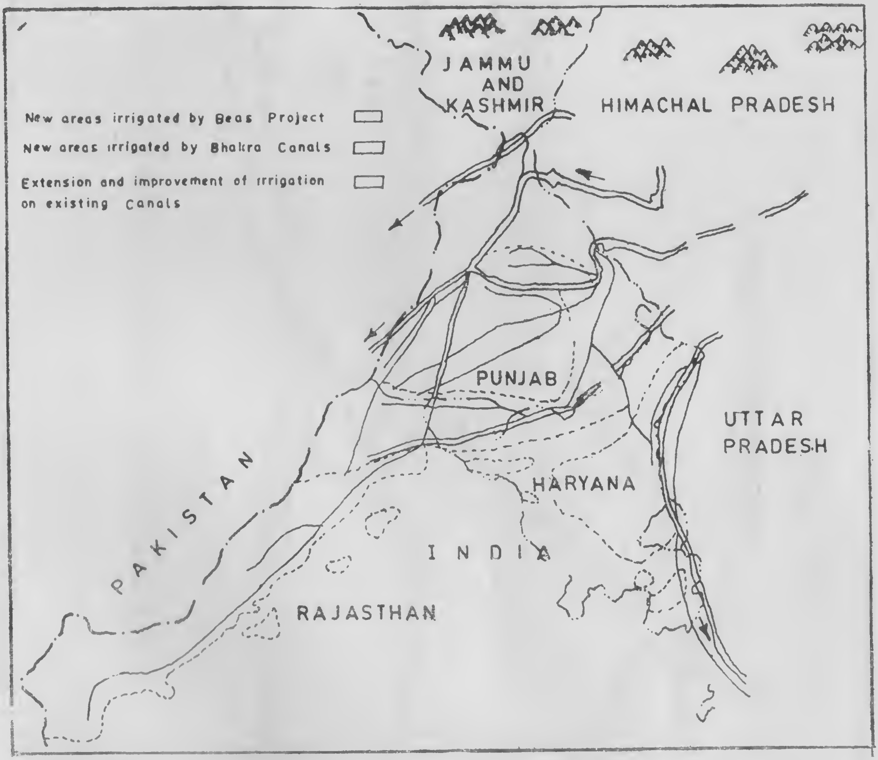


Fig. 4 Showing the Areas irrigated by the Bhakra-Beas Complex

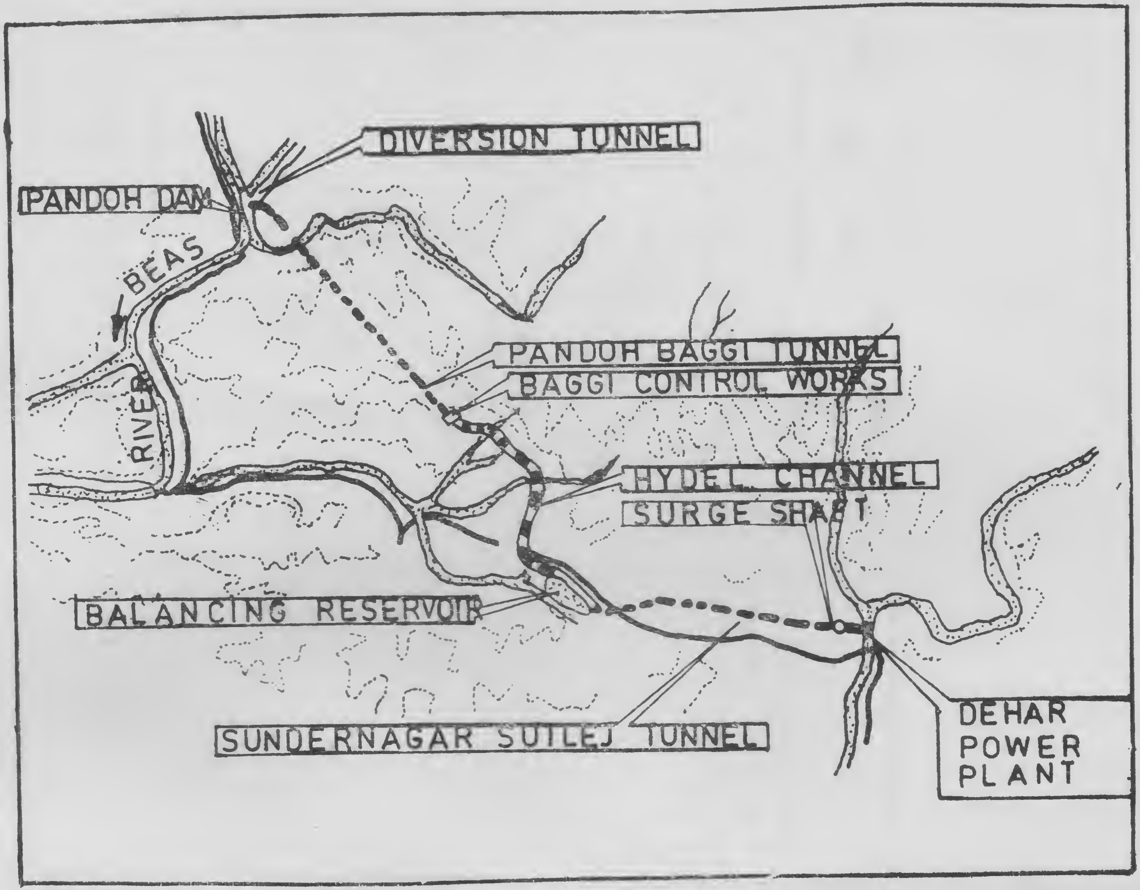


Fig. 5 Showing Beas-Sutlej Link Project—Unit II

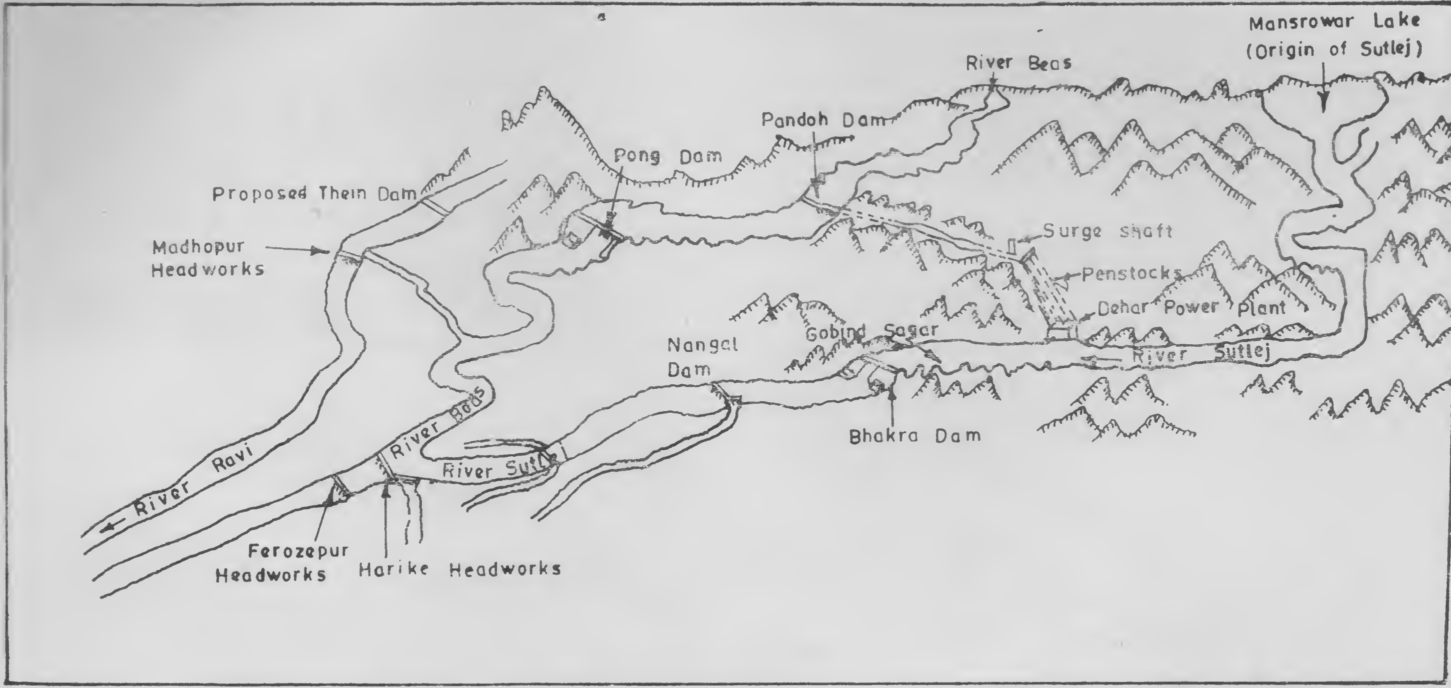
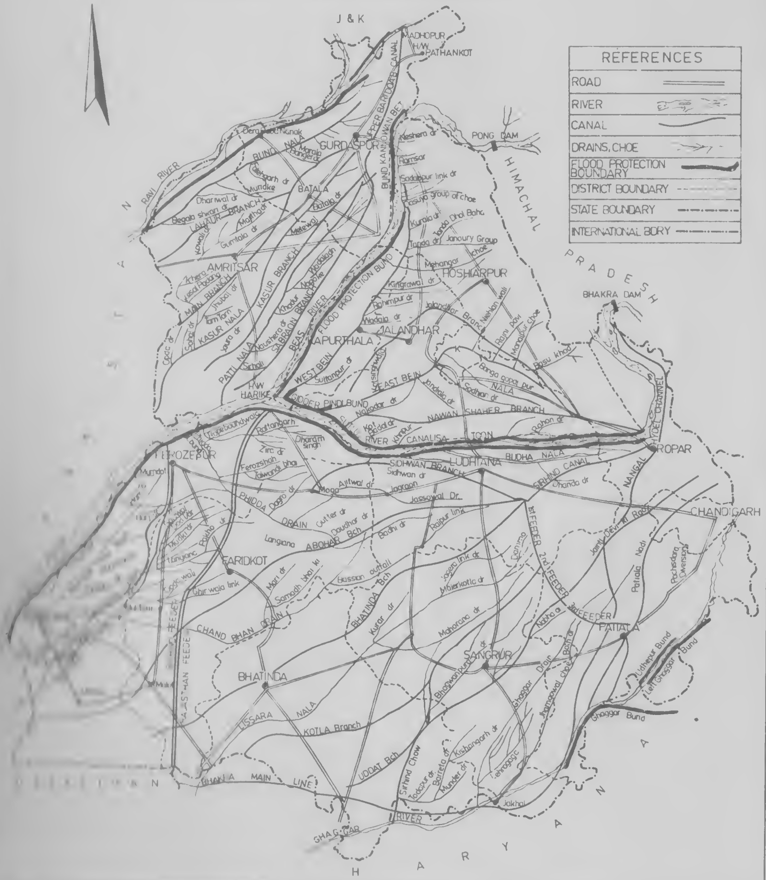


Fig. 6 Showing Master Plan of Development of the Beas and the Ravi Rivers.

SHOWING FLOOD CONTROL AND DRAINAGE OF THE PRESENT DAY, PUNJAB STATE



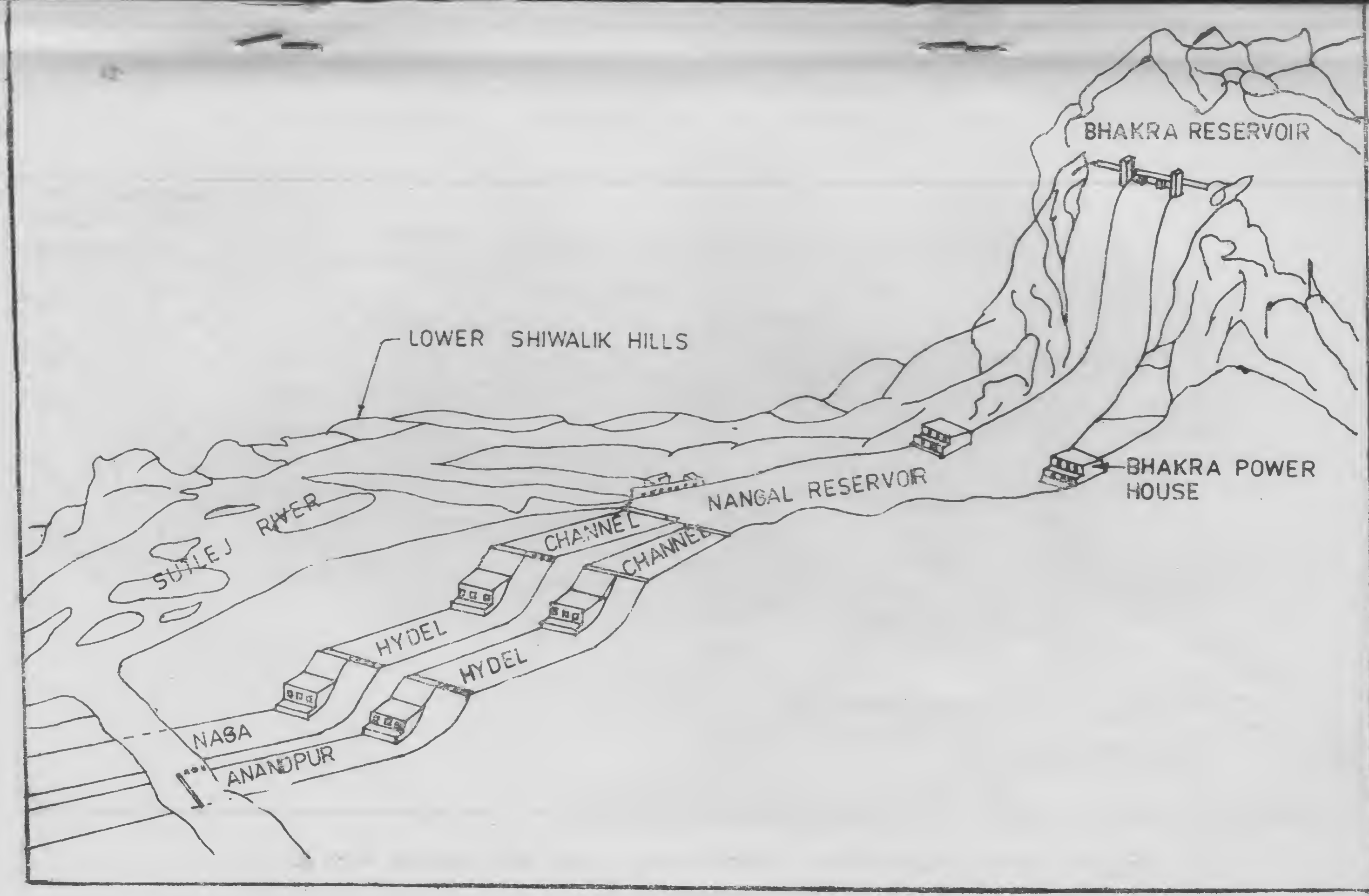


Fig. 7 Showing the view of Anandpur Sahib Hydel Project Nangal Hydel Channel and Bhakra Complex.